INTELLIGENT STREET LIGHTING-
A PLATFORM FOR SMART CITY APPLICATIONS

A THESIS

SUBMITTED IN PARTIAL FULFILMENT OF

THE REQUIREMENT FOR DEGREE OF

MASTER OF ENGINEERING

IN

ILLUMINATION ENGINEERING

SUBMITTED BY

RANAJIT BHATTACHARJEE

EXAMINATION ROLL NO – M4ILN19016

REGISTRATION NO – 140678 of 2017-18

UNDER THE SUPERVISION OF

(Prof) Dr BISWANATH ROY

ELECTRICAL ENGINEERING DEPARTMENT

FACULTY OF ENGINEERING AND TECHNOLOGY

JADAVPUR UNIVERSITY

KOLKATA- 700032

MAY 2019

JADAVPUR UNIVERSITY

FACULTY OF ENGINEERING AND TECHNOLOGY

ELECTRICAL ENGINEERING DEPARTMENT

RECOMMENDATION CERTIFICATE

This is to certify that the thesis entitled **"INTELLIGENT STREET LIGHTING- A PLATFORM FOR SMART CITY APPLICATIONS"** submitted by **RANAJIT BHATTACHARJEE** (Exam Roll No. **M4ILN19016**, Registration No. **140678 of 2017-18**) of this University in partial fulfilment of requirements for the award of Degree of Master of Engineering in Illumination Engineering, Department of Electrical Engineering, is a bona fide record of the work carried out by him under my guidance and supervision.

(Thesis Supervisor)

(Prof) Dr Biswanath Roy
Professor, Electrical Engineering Department,
Jadavpur University,
Kolkata- 700032.

Countersigned

Prof Kesab Bhattacharyya
Head of the Department,
Electrical Engineering Department,
Jadavpur University,
Kolkata- 700032.

Prof Chiranjib Bhattacharjee
Dean,
Faculty of Engineering and Technology,
Jadavpur University,
Kolkata- 700032

JADAVPUR UNIVERSITY

FACULTY OF ENGINEERING AND TECHNOLOGY

ELECTRICAL ENGINEERING DEPARTMENT

CERTIFICATE OF APPROVAL

This foregoing thesis is hereby approved as a creditable study in the area of Illumination Engineering, carried out and presented by **RANAJIT BHATTACHARJEE**, in a manner of satisfactory warrant its acceptance as a pre-requisite to the degree for which it has been submitted. It is notified to be understood that by this approval, the undersigned do not necessarily endorse or approved the thesis only for the purpose for which it has been submitted.

FINAL EXAMINATION FOR EVALUATION OF THESIS.

BOARD OF EXAMINERS

……………………………………......

……………………………………......

(**Signature of Examiners**)

<u>DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS</u>

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of my Master of Engineering in Illumination Engineering studies.

All information in this document have been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by these rules and conduct, I have fully cited and referenced all materials and results that are not original to this work.

NAME : **RANAJIT BHATTACHARJEE**

EXAMINATION ROLL NO. : **M4ILN19016**

THESIS TITLE : **"INTELLIGENT STREET LIGHTING- A PLATFORM FOR SMART CITY APPLICATIONS"**

SIGNATURE & DATE :

ACKNOWLEDGEMENT

A lot of inputs from various sources has helped in making of this thesis and the analysis that has been carried out. I wish to take the opportunity to thank them all. First, I would like to thank **Prof (Dr) Biswanath Roy**, Professor, Electrical Engineering Department, Jadavpur University for providing me his valuable time and helpful suggestions. I would also like to thank him for the guidance and supervision provided in every respect of this thesis work.

I am also grateful to **Mr Chirantan Kumar,** Manager, Bajaj Electricals Limited and **Mr Arijit Sen,** Manager, Bajaj Electricals Limited and their esteemed organisation for providing me an opportunity to undergo internship and learn valuable works from their organisation.

Again, I would like to acknowledge my sincere thanks to **Prof (Dr) Saswati Mazumdar,** Professor, Electrical Engineering Department, Jadavpur University for the valuable suggestions and encouragements during the project work.

I am also thankful to Mr Pradip Pal of Illumination Engineering Laboratory for their warm co-operation during the project work.

Last but not the least, I wish to convey my gratitude to my parents whose love and support have helped me a lot in this project.

Dated- 29/05/2019

Ranajit Bhattacharjee

CONTENTS

List of Figures

List of Tables

Introduction

Various services or amenities are provided by Municipal Corporations. Electric Street light forms an important part of the services provided by them. Electric Street lights provides a basic sense of safety to its citizens and the people driving cars over the streets. It provides a visual guidance of the path which would be very difficult to follow in complete darkness or using car headlamps. Moreover it also adds to the aesthetics and creates a tourism environment for the city.

Providing street lighting is one of the most important and expensive responsibilities of a city. Lighting can account for 10 – 38% of the total energy bill in particular cities worldwide (NYCGP 2009). The estimated gross energy consumption for public lighting is 6,731 million kWh in India for 2010-2011 according to the data provided by Electric Light and Component Manufacturers Association of India (ELCOMA). This is the reason for which street lighting is considered as a critical concern by the developing countries.

With the development, from the usage of arc lamps in 1800's to the usage of HPSV at 21^{st} century the street light has progressed many stages. The main drawback of the conventional lighting system is its continuous usage whether it is required or not, leading to large amount of energy consumption and huge electricity bills. Here comes the application of smart lighting.

Smart lights are the ones which can be communicated easily and efficient management of smart street lighting system saves a considerable amount of energy without compromising the need for safety. Energy efficient technologies can cut street lighting costs dramatically, these savings can reduce the need for a new generating plant and provide the capital for alternative energy solutions. With these savings, the municipalities can also expand their street lighting programmes to other remote areas. In addition improvements in lighting quality and expansion in services can improve safety conditions for the city.

So, the three basic purposes these intelligent lighting serves-

a. Smart lighting
b. Traffic Management
c. Environmental Monitoring

This kind of intelligent lighting provides IT innovations to Civic utilities, real time monitoring of street lamps, centralised control etc. The street light sensors also provides environmental data. This smart luminaires can also be used in conjunction with smart poles which can provide additional amenities to the city dwellers and full fill the requirements of a smart city.

Objective

- To propose comprehensive design scheme of a smart street lighting system to be implemented for a smart city.
- A cost benefit analysis is also provided after calculating the energy savings due to up gradation of system and having a cost comparison between the two projects.
- The 'Simple Payback Period' or the minimum number of years required to recover the initial investment is provided at the end of the thesis.

Scope of Work

Urban Street light in the entire world are dealing with increased energy consumptions and carbon emissions, leading to a climate change. Further energy expenditure are estimated to increase over the years due to an increased demand in electricity and per unit energy costs. Due to inadequate dimming control and low efficiency of luminaires, Current Street lighting system spends lot of energy. Therefore it has become mandatory to implement or design a smart lighting system that is efficient and at the same time environment friendly.

The current street lighting system requires all the luminaires to be functional throughout the night time. The new system aims to control the energy efficient LED lights to turn on only when it is needed and to remain in a dim state otherwise.

This thesis aims to illustrate the components, design and implementation of the proposed smart lighting system. Further study and analysis of the prototype shows its successful implementation, hence the project could be used for a wide-spread development. So this project is not only a profitable one but also a green solution for the sustainable development of the environment.

CHAPTER- 1
URBAN
STREET LIGHTING
SYSTEM

1.1 Street Lighting System

A road surface is made visible by virtue of the amount of light being reflected from the surface and entering the observer's eye; the greater the amount of light entering the eye, greater will be the visual sensation. Thus the illuminance of a road surface, which refers only to the amount of light reaching the surface per unit of area can give no indication of how bright the surface will appear. The brightness will depend on the amount of light being radiated per unit surface area and per unit solid angle in the direction of the observer. This is the Luminance (L) of a road surface and it is the most important parameter for determining visual reliability of a road surface.Colour vision of objects is not so important in case of road lighting. It is the luminance contrast that is the difference of luminance between an object and its background, helps in the detection of obstacles. Road lighting normally produces negative contrasts i.e. the object is darker than its surroundings. [1]

1.1.1 Objectives of Road lighting

- The prime objective is safety and security of the citizens.
- Visual guidance of the shape of the road as shown in Fig 1.1. The motorists should be able to identify the curves, bends and change in road width.
- Visual performance of the road users including motorists, cyclists and pedestrians.
- Visual comfort to the road users.

Fig 1.1: Road lighting luminaires showing visual guidance of the path

1.1.2 Visual Performance

i. Average Luminance (L_{av})

There is an increase in the visual performance arising from an increase in back-ground luminance, as the chances of objects being detected increases sharply. Another phenomenon is that a decrease in the vertical illuminance on the object rises the lower limit of the object reflectance at which an object becomes undetectable. So visual performance improves with the decrease in vertical illuminance. Therefore the average road surface luminance is considered an important lighting parameter. [1]

ii. Uniformity of Luminance

To ensure a certain minimum value of the luminance at all points on the road, the difference between the average and minimum road surface luminance should not be too great. A certain minimum value of the ratio of minimum to average road surface luminance should be specified. This is known as overall uniformity (U_0).
The smaller the ratio, the poorer will be the uniformity and worse will be the visual performance. [1]

iii. Glare

Light coming from a glare source that is too close to the line of sight is partly scattered in the eye and that part of it falling unfocused on the focused image produces a visual sensation that can be likened to the drawing of a bright veil across the field of vision. This veil can be considered as having a luminance, the equivalent veiling luminance proportional to the degree of scatter in the direction of retina. The overall effect of glare on the visual performance can now be determined by adding the total veiling luminance to the object luminance and back-ground luminance forming the contrast of the object. The just perceivable contrast for a standard object is termed as “threshold contrast”. An object that can just be seen when there is no glare (threshold contrast) cannot be seen when glare is present unless the actual contrast is increased. The amount of extra contrast required to make the object just visible under glare conditions dividing by effective contrast is termed as “threshold increment” (TI). [1]

Summarising three basic road lighting parameters which influences the degree of visual performance of the road user are:

1. Average road surface luminance.
2. Overall Uniformity.
3. Threshold Increment.

1.1.3 Visual Comfort

i. Lighting level

The degree of visual comfort experienced by a road user is very much dependent upon the value of average road surface luminance to which he is adopted; the higher this luminance the more comfortable he will feel in the performance of the driving task. Thus the average road surface luminance (L_{av}) is considered an important lighting parameter in connection with visual comfort aspect of road lighting. [1]

ii. Uniformity of Luminance

Visual comfort is also known to be influenced by the unevenness of road lighting. This results in a continuously repeated sequence of alternate dark and bright bands which is very disturbing to a passing driver. The severity of this effect is determined by another lighting parameter called longitudinal Uniformity (U_l). U_l is defined as a ratio of minimum to maximum road surface luminance on a line parallel to the axis of the road passing through observer position. [1]

iii. Glare

Glare has of course a disturbing effect on the visual comfort of a driver. The degree of visual discomfort experienced is dependent upon the design of the luminaire used in road lighting installation and design of the installation as a whole. CIE tried to describe one factor which describes the degree of control possessed by the installation with respect to the discomfort glare and termed it as Glare control mark (G). The higher the value of glare control mark, higher will be the freedom from discomfort glare. [1]

Summarising three basic lighting parameter have been used for describing the visual comfort aspect of road lighting installations. These are:

1. Average road surface luminance.
2. Longitudinal uniformity.
3. Glare control mark.

Apart from these there are other two lighting parameters used for road lighting design.

1. Surrounding Ratio (SR)

   Surrounding Ratio is defined as the ratio of the average luminance of the road surface to the average luminance of the pedestrian path. SR is around 0.5 as recommended by CIE.

2. Unit Power Density (UPD)

$$UPD = \frac{\left(Number\ of\ luminaries\ per\ cycle * \frac{Wattage}{luminarie}\right) * 1.15}{Span * Width}$$

   Number of luminaries per cycle
   1 for Single sided arrangement
   2 for staggered and opposite arrangement

   Wattage include Lamp wattage plus ballast loss
   15% increment from base value is given to account for the reduced span in curved portion of the entire road.
   UPD is represented in W/m^2

1.1.4 Effect of Road Surface

Road surface plays a very important role in road lighting design. The same illuminance can result in a different visual scene due to the difference in road surfaces.

The choice of the parameters used to describe the reflection characteristics of a road surface is based on two quantities; lightness of road surface (degree of greyness from white to black) and specularity (Shininess of the road surface).

The parameters used in the CIE system are

Q_0- Average luminance co-efficient for the lightness of road surface.

S1, S2- Specular factors to describe the specularity of road surface.

If Q_0 value is high, the road surface is light otherwise the surface is dark for low values of Q_0. Similarly larger the value of S1, more specular is the road surface. [1]

1.1.5 Road lighting Design input parameters

The various data are provided to the software as input during road lighting design are listed below. Few terms are explained in the Fig 1.2 below.

i. Street Light luminaires (Wattage and type of luminaire)
ii. Maintenance factor of the road lighting installations.
iii. Width of the road.
iv. Type of arrangement of street lighting poles.
v. Mounting height of the luminaires.
vi. Spacing between each street poles.
vii. Street light pole set back distance.
viii. Overhang of the luminaires.
ix. Angle of tilt for the luminaires.
x. Type of road according to the classification and type of street coating.

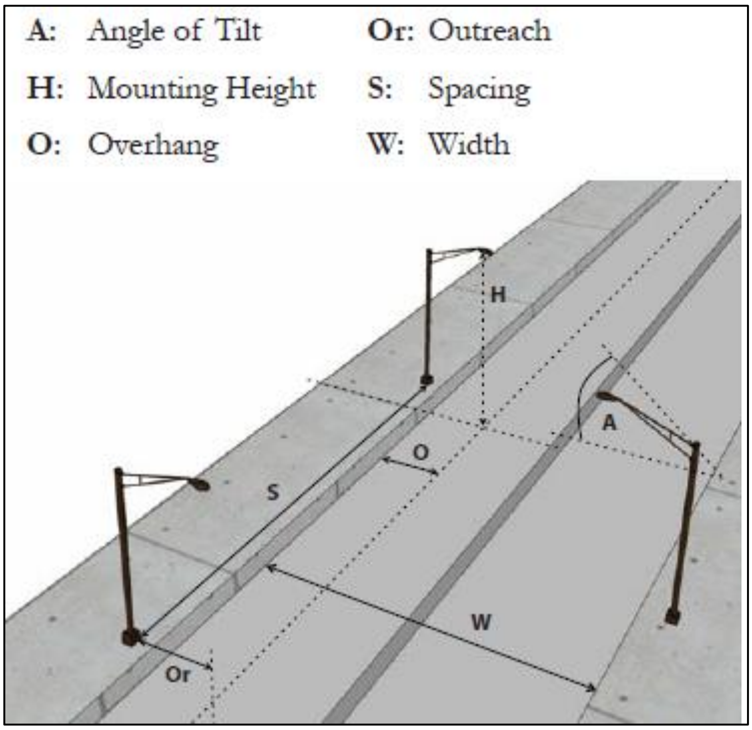


Fig 1.2: Diagram describing road lighting design parameters

There are four fundamental arrangement of street lighting poles as recognised in road lighting (BIS 1981) as explained in Fig 1.3 [2]

1. **Single sided arrangement**- all the luminaires are on one side of the road. This is recommended where width of the road is equal to or less than the mounting height.
2. **Staggered arrangement**- all the luminaires are placed on either side of the road in a zigzag formation. This is recommended when the road width is 1 to 1.5 times the mounting height.

3. **Opposite arrangement-** all the luminaires are on either side of the road opposite to one another. This is recommended for road width more than 1.5times the mounting height.
4. **Central verge arrangement-** all the luminaires are placed on the axis of the road. This is recommended for narrow road width not exceeding the mounting height of the luminaires.

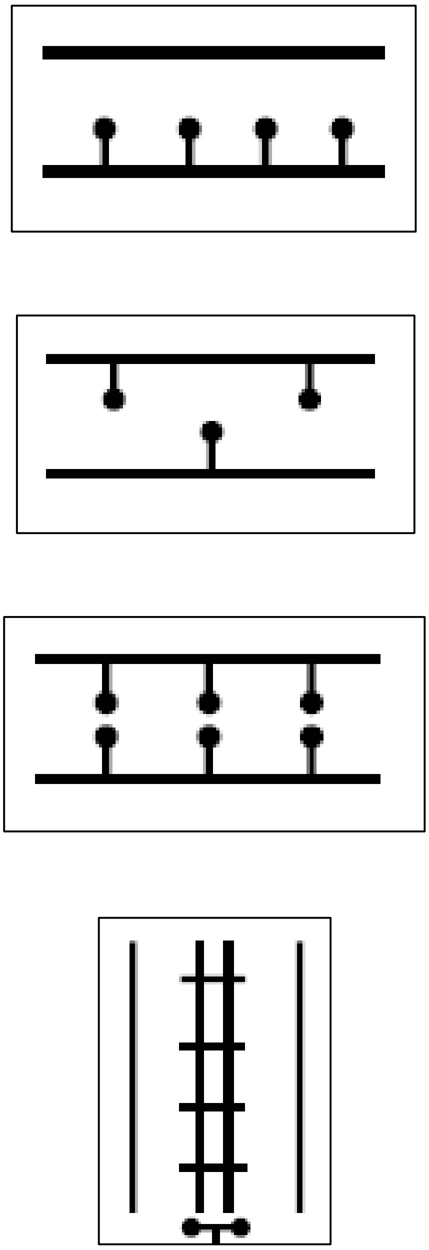


Fig 1.3: Types of arrangement of street luminaires

1.1.6 Classification of Roads according to CIE 115:2010 [3]

A Technical report on lighting of roads for Motors and pedestrian traffic. The M Lighting class depends on traffic speed, volume, composition, ambient luminance and other factors.

Sl. No	Description of Roads	Lighting Class
1	High speed roads with separate carriageway, free of crossings at grade and with complete access control. Traffic density of road layout: High.	M1
2	High speed roads, traffic control with presence of signal and separation of different road users into lanes. Traffic density of road layout: Medium.	M2
3	Important urban traffic roads, radical roads, distinct distribution roads. Traffic density: Low.	M3
4	Connecting less important roads, distributor roads. Separation of roads into different lanes is poor.	M4
5	Residential major roads which leads to connecting roads, separation of roads into different lanes.	M5

1.1.7 Lighting Classification for different Road types- CIE classification [3]

Sl. No	Lighting Class	All roads			Roads with few junctions	Roads with foot ways
		L_{av}	U_0	U_l (min)	TI % (max)	Surround ratio (SR)
1	M1	2.0	0.4	0.7	10	0.5
2	M2	1.5	0.4	0.7	10	0.5
3	M3	1.0	0.4	0.5	10	0.5
4	M4	0.75	0.4	-	15	-
5	M5	0.5	0.4	0.4	15	-

1.1.8 Classification of Roads according to IS 1944:1975 [2]

Sl. No	Group	Description of Roads
1	A1	For very important with rapid and dense traffic where the only considerations are the safety and speed of the traffic and the comfort of drivers.
2	A2	For other main roads with considerable mixed traffic like main city streets, arterial roads and thoroughfares.
3	B1	For secondary roads with considerable traffic such as principal local traffic routes, shopping streets etc.
4	B2	For secondary roads with light traffic.
5	C	Lighting for residential and unclassified roads not included in the previous groups.
6	D	Lighting for bridges and flyovers.
7	E	Lighting for towns and city centres.
8	F	Lighting for roads with special requirements such as roads near airport and railways.

1.1.9 Lighting recommendations for different road types- IS classification [3]

Sl. No	Group	Average Illuminance on road surface (lux)	Uniformity Ratio (E_{min}/E_{avg})	Transverse Uniformity (E_{min}/E_{max})
1	A1	30	0.4	0.33
2	A2	15	0.4	0.33
3	B1	8	0.3	0.2
4	B2	4	0.3	0.2

1.1.10 Selection Criteria of Luminaires for Road Lighting [3]

1. Mechanical characteristics.
2. Electrical characteristic.
3. Required lamp types.
4. Ambient operation temperature.
5. Required IP rating.
6. Air resistance.
7. Component and accessories exchangeability**.**
8. Mounting functionality.
9. Material requirement.

1.1.11 Luminaire Photometric characteristics [3]

1. **Throw**- the extent to which the light from the luminaire is distributed along the road.
   Three degrees of throw are specified as follows:

   $\gamma_{max} < 60°$: Short throw

   $60° < \gamma_{max} < 70°$: Intermediate throw

   $\gamma_{max} > 70°$: Long throw.

2. **Spread**- the amount of sideways spread of light across a road.
   Three degrees of spread are defined as follows:

   $\gamma 90 < 45°$: narrow spread

   $45° < \gamma 90 < 55°$: average spread

   $\gamma 90 > 55°$: broad spread

3. **Control**- the extent of the facility for controlling glare from the luminaire.
   Three degrees of control are specified:
   SLI<2: limited control
   2<SLI<4: moderate control
   SLI>4: tight control

These photometric terms are explained in Fig 1.4 below.

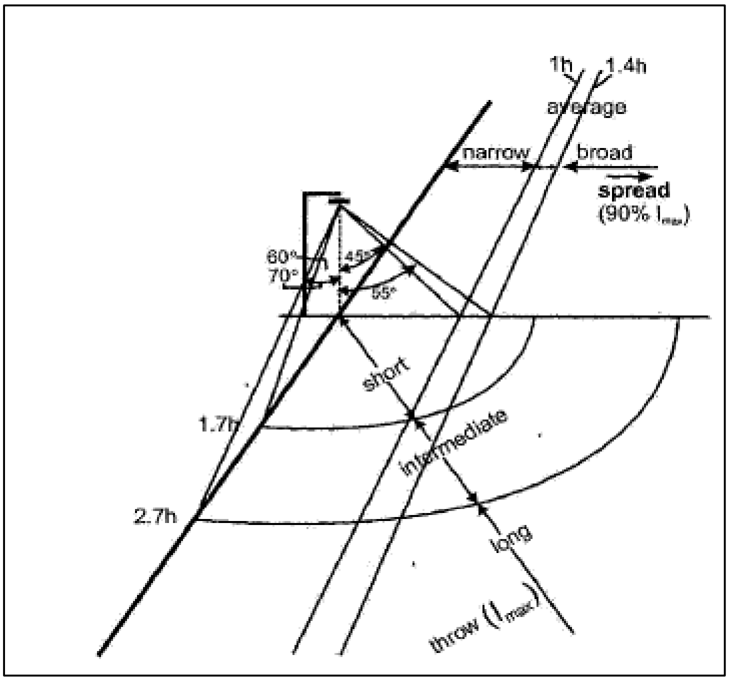


Fig 1.4: Degrees of Throw and Spread as recommended by CIE

1.2 Retrofitting or Up gradation of existing road lighting installations

Based on the purpose and lighting requirements of the roadway as well as age of the existing lighting infrastructure, decisions have to be taken whether new design and installations of street lighting is required or whether project goals can be implemented by retrofitting the existing lighting system.

Retrofitting is generally considered for energy and maintenance savings. Opportunities for significant efficiency improvements are limited in these cases, since the pole locations does not change.

Retrofit strategies: [3]

a. Determine the required maintained light level. As the industry proverb goes, "Light is for people, not buildings." The lighting system's first task is to provide sufficient quantity and quality of light for occupants to perform relevant tasks. In existing installations, this will require a lighting system audit.

b. Determine the qualitative lighting requirements. Identify all quality issues such as glare, colour, aesthetics, distribution and attendant factors (such as surface reflectance and ceiling heights) that must be given priority during equipment selection and design.

c. Identify equipment options that produce the desired maintained quantity and quality of light and also save energy. Equipment options will include lamps, ballasts, and luminaires and advanced controls (occupancy sensors, dimming controls, photocells, lighting management systems etc.).

d. Identify strategies that support the goal of reducing energy consumption, such as planned lighting maintenance, repainting room surfaces to give them a higher reflectance (if appropriate) and developing a written lighting energy policy.

e. Choose the best package of equipment and strategies that will achieve the desired lighting goals while delivering desired economic performance.

1.3 Problems associated with conventional HPSV and WLED lighting system

In the process of upgrading our city to a Smart one, smart street luminaires are implemented for a stretch of the road for increased sense of safety and security. We are adding a control mechanism to our conventional LED luminaires and we are also getting some benefits due to the huge investment in the retrofitting project. So, now we have to know the reasons for which we are shifting from a conventional to a smart street lighting system- [4]

1. **Full Control over the lighting infrastructure**- we can get control over the system by switching or dimming the luminaires individually or in a group, adaptable during any festival or any kind of maintenance work, control over the luminaires during emergency or any natural calamity.

2. **Remote Monitoring, control and management**- With remote monitoring, we can trace individual luminaries on the map and know their real time status. We can provide commands from our software architecture to a luminaire or a group of luminaire to change their status and have control over the entire lighting system.

3. **Energy consumption statistics**- we can utilise various data available from software architecture like operating hours, sensor information, time of glow with full intensity or reduced intensity to calculate power usage, estimated energy savings etc.

4. **Failure identification-** we can get exact real time information for any failure of a luminaire with exact location and sounds an alarm to make the operators alert.

5. **No night patrols required**- Since we are getting all the information of a luminaire over a screen, no patrolling will be required for the maintenance team and we can have a considerable amount of saving with reduced maintenance activity.

The specific performance of a High Intensity discharge (HID) lamp dimming system are dependent on the circuitry employed with specific ballasts and lamps. The use of an HPSV or Metal Halide lamps on dimming system can result in issues such as poor lamp performance, colour shift etc. To avoid reduced lamp life, the dimming of a HID lamp should not exceed 30% for HPSV and 50% for metal halide. [2]

1.4 Integration of Lighting control

There are a number of factors that need to be considered in any control system; these are the inputs to system, how the system controls the lighting equipment and the control process that decides how a particular set of inputs will impact on the lighting. Thus for a control system to work it must have:

- Input devices: such as switches, presence detectors, timers and photocells
- Control processes: these may consist of a simple wiring network through to a computer based control system
- Controlled luminaires: the system may control luminaires in a number of ways, from simply switching them on and off to dimming the lamp and in more complex systems causing movement and colour changes. [4]

Lighting control for street light luminaires

- On/off control
- Occupancy recognition
- Scheduling
- Dimming
- Lumen depreciation compensation

On/off control- It is the basic control function with turning lights on or off. The degree to which this function is performed depends on other variables such as occupancy recognition or scheduling.

Occupancy recognition- This process is typically used to turn lights on when motion is detected and off automatically after a certain period of time when they are no longer present. The principal technologies used for detection are ultrasonic and passive infrared. Occupancy detection can have significant amount of energy saving by preventing the waste caused by turning lights on when they are not needed.

Scheduling- Scheduling is time-based function. Illumination over a particular area is activated or extinguished according to a pre-determined schedule.

Dimming- There are basically three types of lamp dimming system.

Step-level line voltage dimming circuits work by changing the applied voltage in the street lighting system. A variable voltage low loss transformer is installed at switching points and has timer control and a power factor correcting mechanism.

Bi-level dimming electronically modifies the object into a low or high near the lamp by employing electronic low or high frequency switching circuits.

Continuous dimming systems reduce the line voltage continuously through variable step transformers/ variable reactors/wave choppers using electronic circuits.

Lamp depreciation compensation- The output of an electric luminaire diminishes over time which is termed as lamp lumen depreciation. Light is lost due to the build-up of dust and dirt on lamps and the reflective surfaces of luminaires. Regular maintenance of the system can often be a major source of energy and cost savings, as well as improved lighting quality.

So a large number of control options are available for the street light luminaires. Again these can be a manual or automatic control options. Manual lighting control includes lighting panel board control, circuit breakers control and switches. Automatic controls are programmed to take a certain action at a specified time or an event initiated.

CHAPTER- 2

SMART CITY- A GENERAL DISCUSSION

2.1 What is a Smart City?

There is no universally accepted definition of Smart City. The conceptualisation of Smart City varies from country to country, people to people depending on the level of development. The picture of a Smart city contains a wish list of infrastructure and services that a city dweller expects to enjoy. To provide the need of the citizens municipal bodies have started developing the entire urban ecosystem which is represented by four pillars of comprehensive development, physical, social and economic infrastructure.
In the objective of the Smart City mission, the objective is to promote cities with core infrastructure development with a clean and sustainable environment, provide 'smart' solutions with better quality of life to its citizens.

The core infrastructure element of the Smart City as shown in Fig 2.1 include: [5]

i. Adequate water supply.
ii. Assured electricity supply.
iii. Sanitation, including solid waste management.
iv. Efficient urban mobility and urban transport.
v. Affordable housing especially for the poor.
vi. Robust IT connectivity and digitalisation.
vii. E-governance and citizen participation.
viii. Sustainable environment.
ix. Safety and security to its citizens.
x. Health and education.

2.2 Smart City features and strategy [5]

Some typical features of comprehensive development in Smart Cities are described below.

1. Promoting mixed land use in area based developments–planning for 'unplanned areas' containing a range of compatible activities and land uses close to one another in order to make land use more efficient. The States will enable some flexibility in land use and building bye-laws to adapt to change.
2. Housing and inclusiveness - expand housing opportunities for all.
3. Creating walkable localities –reduce congestion, air pollution and resource depletion, boost local economy, promote interactions and ensure security. The road network is created or refurbished not only for vehicles and public transport, but also for pedestrians and cyclists, and necessary administrative services are offered within walking or cycling distance.
4. Preserving and developing open spaces - parks, playgrounds, and recreational spaces in order to enhance the quality of life of citizens, reduce the urban heat effects in Areas and generally promote eco-balance.

5. Promoting a variety of transport options - Transit Oriented Development (TOD), public transport and last mile para-transport connectivity.
6. Making governance citizen-friendly and cost effective - increasingly rely on online services to bring about accountability and transparency, especially using mobiles to reduce cost of services and providing services without having to go to municipal offices. Forming e-groups to listen to people and obtain feedback and use online monitoring of programs and activities with the aid of cyber tour of worksites.
7. Giving an identity to the city - based on its main economic activity, such as local cuisine, health, education, arts and craft, culture, sports goods, furniture, hosiery, textile, dairy, etc.
8. Applying Smart Solutions to infrastructure and services in area-based development in order to make them better. For example, making Areas less vulnerable to disasters, using fewer resources, and providing cheaper services.

The strategic components of area-based development in the Smart Cities Mission are city improvement (retrofitting), city renewal (redevelopment) and city extension (Greenfield development) plus a Pan-city initiative in which Smart Solutions are applied covering larger parts of the city. Below are given the Deion's of the three models of Area-based smart city development:

- Retrofitting will introduce planning in an existing built-up area to achieve smart city objectives, along with other objectives, to make the existing area more efficient and liveable. In retrofitting, an area consisting of more than 500 acres will be identified by the city in consultation with citizens. Depending on the existing level of infrastructure services in the identified area and the vision of the residents, the cities will prepare a strategy to become smart. Since existing structures are largely to remain intact in this model, it is expected that more intensive infrastructure service levels and a large number of smart applications will be packed into the retrofitted smart city. This strategy may also be completed in a shorter time frame, leading to its replication in another part of the city.
- Redevelopment will effect a replacement of the existing built-up environment and enable co-creation of a new layout with enhanced infrastructure using mixed land use and increased density. Redevelopment envisages an area of more than 50 acres, identified by Urban Local Bodies (ULBs) in consultation with citizens. For instance, a new layout plan of the identified area will be prepared with mixed land-use, higher FSI and high ground coverage
- Greenfield development will introduce most of the Smart Solutions in a previously vacant area (more than 250 acres) using innovative planning, plan financing and plan implementation tools (e.g. land pooling/ land reconstitution) with provision for affordable housing, especially for the poor. Greenfield developments are required around cities in order to address the needs of the expanding population. One well known example is the GIFT City in Gujarat.
- Unlike retrofitting and redevelopment, Greenfield developments could be located either within the limits of the ULB or within the limits of the local Urban Development Authority (UDA).
- Pan-city development envisages application of selected Smart Solutions to the existing city-wide infrastructure. Application of Smart Solutions will involve the use of technology,

information and data to make infrastructure and services better. For example, applying Smart Solutions in the transport sector (intelligent traffic management system) and reducing average commute time or cost of citizens will have positive effects on productivity and quality of life of citizens. Another example can be waste water recycling and smart metering which can make a huge contribution to better water management in the city.

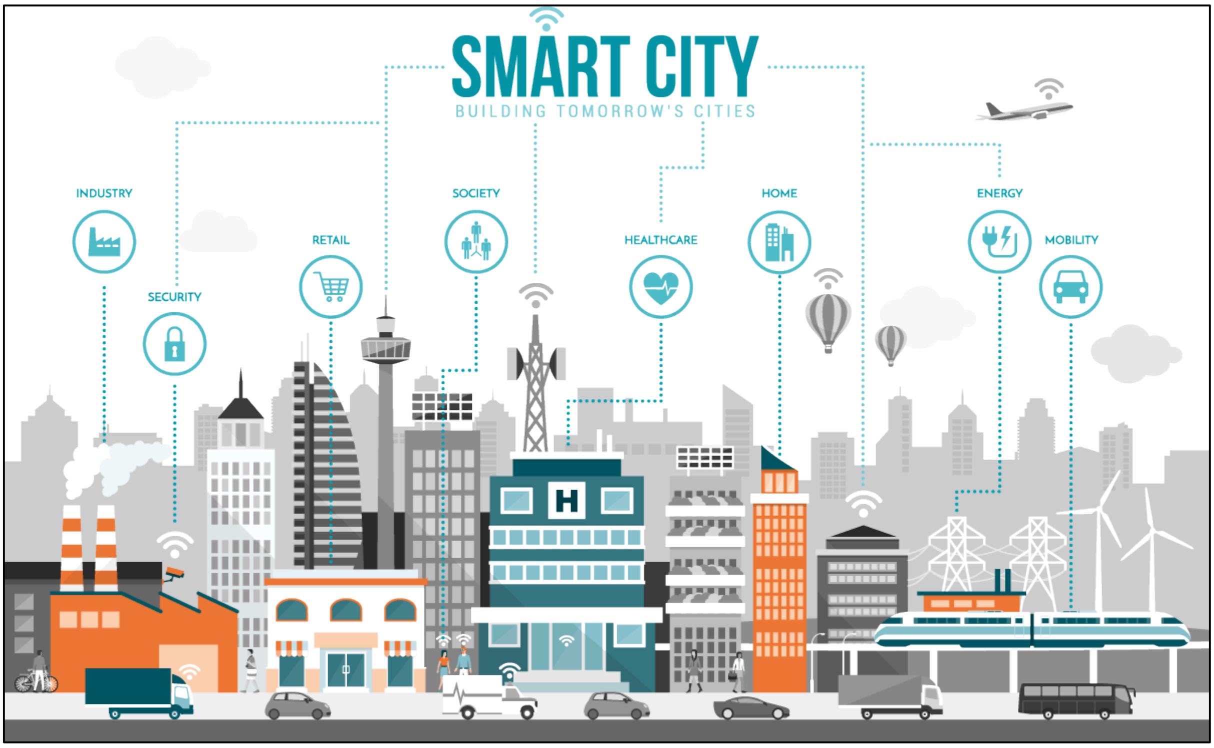


Fig 2.1: Diagram describing Smart City features

2.3 Smart City Mission Solutions [5]

1. **E-governance and citizens services**
    a. Public information, grievance redressal.
    b. Electronic service delivery.
    c. Citizen’s engagement.
    d. Video crime Monitoring.

2. **Waste Management**
    a. Waste to energy and fuel.
    b. Waste to compost.
    c. Waste water to be treated.
    d. Recycling and reduction of wastes.

3. **Water Management**
    a. Smart meters and maintenance.
    b. Preventive measures.
    c. Water quality monitoring.

4. **Energy Management**
    a. Smart Meters and management.
    b. Renewable sources of energy.
    c. Energy efficient and green buildings.

5. **Urban Mobility**
    a. Smart Parking
    b. Intelligent traffic management.
    c. Integrated multi modal transport.

6. **Others**
    a. Tele-medicine and Tele education.
    b. Incubation/trade facilitation centre.
    c. Skill development centres.

Among the various kinds of Smart solutions, Smart Street lighting solutions comes under the topic of Energy Management. It is being considered as an energy efficient procedure under the retrofitting or re-development strategy of the Urban Street lighting project.

CHAPTER- 3
SMART
STREET LIGHTING
SYSTEM

3.1 System Components

The additional products which are required to make a public lighting system fully intelligent are- Sensors, Wireless lighting controller, Gateway & software architecture.

Sensors- these are basically passive infra-red (PIR) sensors which detects the presence of people or cars in their zones. There must be proper selectivity in the sensors to have a particular range of detection in the streets and to differentiate between cars and animals.

Wireless lighting controller- this device helps to control the lumen output of the luminaries. Based upon the needs or the traffic, the sensor sends a signal to the lighting controller to change its output accordingly.

Gateway- it is a device which acts as an intervening medium between the lighting controllers and the lighting management software.

Software Architecture- It is a software platform that helps in the real time monitoring of all street lamps within the city or particular zone. It provides the platform for remote monitoring and helps to reduce the manpower required for maintenance of street lamps. It also provides self-diagnosis of any fault related to street lamps connected to an alarm system.

The solution given by the company for smart street lighting solutions consists of 3 types of components or services as shown in Fig 3.1.

1. Hardware Components
2. Software Components
3. Supporting Services

Fig 3.1: Components and services of a fully intelligent public lighting system

3.1.1 Hardware components-

1. **Citysense**

Citysense [6] (Fig 3.2) offers on-demand adaptive lighting, making the street lights adjust their brightness based on the presence of pedestrians, cyclists or cars. Using a real-time mesh network, Citysense triggers neighbouring lights and creates a safe circle of light around an occupant. The specifications of Citysense street light sensor are provided in the Table 3.1below-

Fig 3.2: Citysense Sensor

Table 3.1 Technical Specifications of 'Citysense' Sensor

Parameter	Details
Controller	ARM Cortex-M3 CPU
Product Mounting	On the pole
Dimming Control	0-10V and DALI (DALI isolated for safety); software switchable
Housing	IP 65, Weatherproof and Fireproof (UL94V0) Housing
Dimensions	100mm x 125mm x 95mm
Product Compatibility	Wireless Compatibility with all products
Wireless Communication	2.4 GHz, IEEE 802.15.4 self-forming self-healing wireless network
Surge Protection	110 Joule (6kA), 12kV Combination Wave
Operating Conditions	-20°C to +70°C ambient
Power Supply	230 VAC or 115VAC, 50/60 Hz
Typical Consumption	3W typical
Lamp Switching Capacity	2400VA (relay)

The adjustments of the Citysense sensor to human presence happens automatically. Interference factors such as small animals or moving trees are filtered out. The selectivity of the sensors to human beings and not to the presence of animals is mandatory otherwise the luminaires will get false on due to animals or any wind movement or rains.

As these are basically passive infra-red sensors the range of wavelengths to which these must respond are provided in-built at the time of manufacturing. In this way these sensors can differentiate between the presence of human beings and others as shown in Fig 3.3. [6]

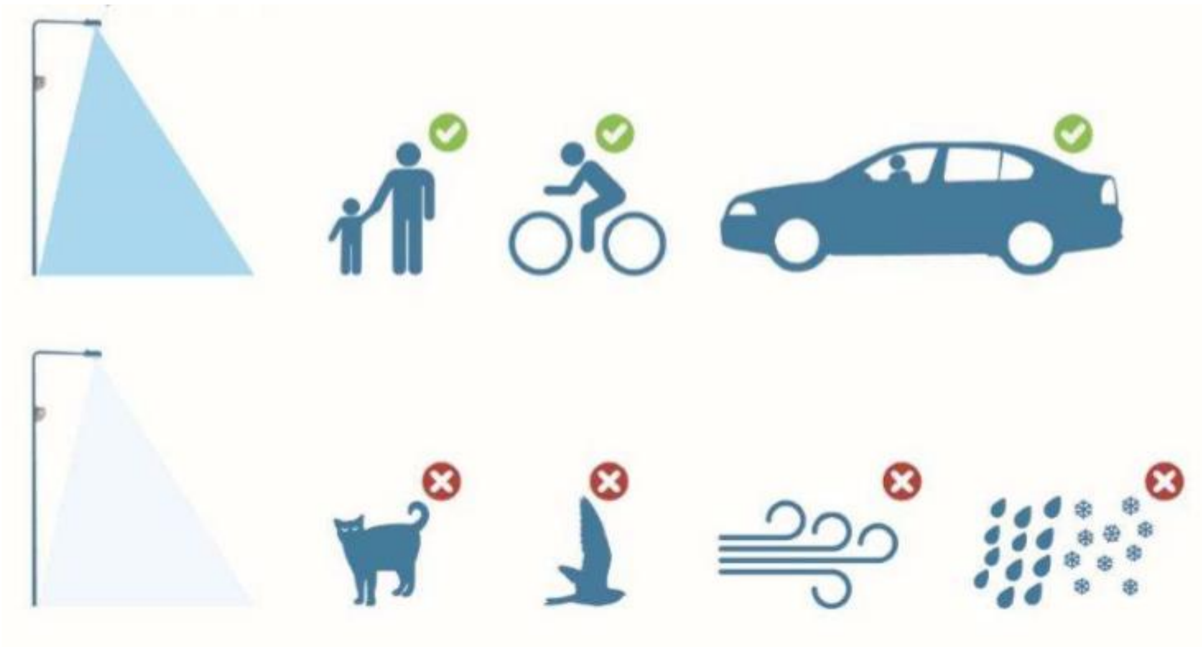


Fig 3.3: Figure describing the response of Citysense Sensor to particular objects

There are various kinds of roads, it can be a highway or a road for pedestrians, a road with or without pavement, a busy junction or a straight road, presence or absence of small tress etc. Depending upon these factors the placing of the sensor has to be determined and the tilt angle has to be adjusted to have a particular reach or selectivity zone of the sensors (Fig 3.4). [6]

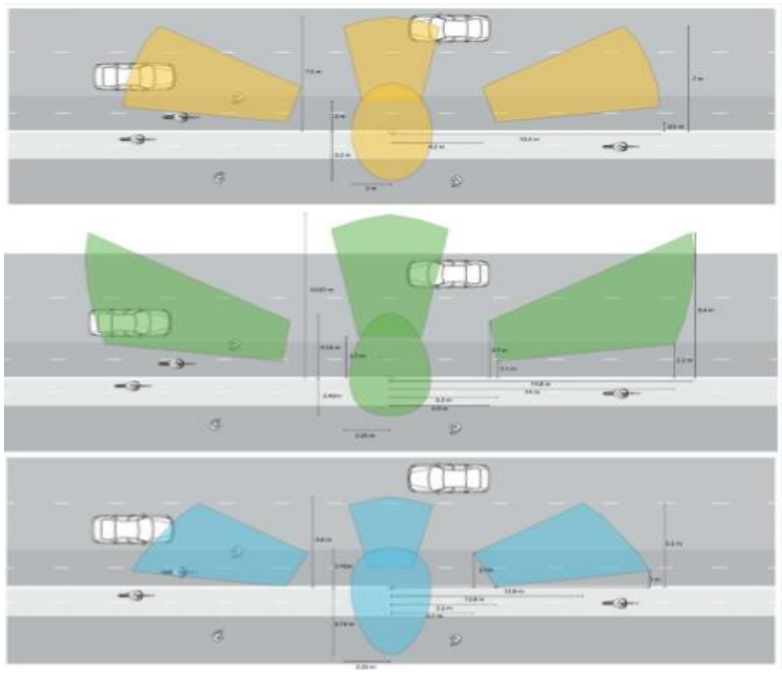


Fig 3.4: Range of Sensor Module

2. SkyLite

SkyLite (Fig 3.5) is the wireless lighting controller that operates the street lights based on client needs and programmable schedules. This product can be used in two ways- one integrated with the street light LED luminaire or in conjunction with the CitySense street light sensor mounted on the pole. As it receives a signal from the sensor, it changes its output configuration to make the luminaire dim or glow fully at its rated efficiency. The technical specifications are provided in Table 3.2 below. [6]

Table 3.2: Technical Specification of 'SkyLite'

Parameter	Details	
	Internal	*External*
Controller	ARM Cortex M3 CPU	
Antenna	External	Built-in
Product Mounting	Inside Luminaire	On the Pole
Dimming Control	0-10V or DALI, software switchable	
IP Rating	IP20	IP65
Housing	Weatherproof and Fireproof Housing (UL94V0) Housing	
Dimension	120x55x29 mm	60x110x60 mm
Product Compatibility	Wireless compatibility with all products	
Wireless Communication	2.4 GHz, IEEE 802.15.4 self-forming self-healing wireless network	
Surge Protection	110 Joule (6 kA), 12kV Combination wave	
Operating Conditions	-20°C to +70°C ambient	
Power Supply	230 VAC or 115 VAC, 50/60 Hz	
Typical Consumption	2W typical	

Fig 3.5: 'SkyLite' Luminaire Controller

Integrated Wireless Driver

Wireless LED driver (Fig 3.6) make it easy to convert conventional LED street light fixtures into a smart connected street lighting system. This can also be considered as a built-in lighting controller that helps the management to install an intelligent and connected lighting. This driver allow access to all driver and luminaire data previously unavailable to the OEM's and end-users. Additionally there is a significant reduction in cost and complexity due to all-in-one integrated component. [6]

Fig 3.6: Integrated Wireless Driver

The various ways in which the driver can perform in different configuration are- [6]

- Fixed Dimming.
- Dynamic Dimming (in combination with CitySense).
- Scheduled Dimming.
- Operation based on Astronomical-clock.
- Over the air Update.
- Remotely configure the output current.

Various wattages of the integrated driver along with their output DC current and voltage levels are given in Table 3.3 below-

Table 3.3 Values of output DC current & voltages of integrated driver

Wattages	Current (mA)	Voltage (V dc)
40W	250-1500mA	10-57V
60W	500-2100mA	10-57V
100W	500-1500mA	50-150V
150W	500-1500mA	70-280V
200W	500-1400mA	80-280V

The analysis of the data received from the driver helps us to know about various parameters required for continuous operation and maintenance of the connected street lighting. [6]

- Helps us to know about the driver temperature.
- Get the LED module temperature.
- Whether load is connected or disconnected.
- Lamp failure.
- Internal driver overheat.
- Overcurrent protection (OCP).
- Overvoltage protection (OVP).
- Total working hours.

Other specifications of the wireless driver are given in the Table 3.4 below-

Table 3.4 Various specifications of Integrated driver

Parameter	Details
Output Type	CC
LED Thermal NTC output	Yes
LED Driver thermal protection	Yes
Safety Standards	ENEC,BIS,FCC,WPC
IP	IP65
Surge	6kV
Isolated	Yes
THD	<20%

3. Gateway

A gateway (Fig 3.7) is a device designed for interfacing between two communication networks that use different protocols such as BACnet to DALI or DMX 512 to 0-10V DC. A gateway may contain devices such as protocol translators, impedance matching devices, rate converters, fault isolators as necessary to provide system interoperability. It also requires the establishment of mutually acceptable administrative procedures between both networks.

Therefore it acts as a bridge between the devices and the internet. Mounted on the pole mainly at a junction at 5m pole height. It allows a maximum connection of 200 devices per gateway. Various technical specifications is provided in Table 3.5 [6]

Table 3.5 Technical specifications of 'Gateway'

Parameter	Details
Controller	ARM Cortex A9 CPU
Antenna	2x2.4 GHz (Lighting Control Network and WiFi)
Communication	2/3/4G (GSM), WiFi
Product Mounting	On the pole
Housing	IP 65, Weatherproof and Fireproof (UL94V0) Housing
Dimensions	230mm x 130mm x 90mm
Product Compatibility	Wireless compatibility with all products
Wireless Communication	2.4GHz, IEEE 802.15.4 self-forming self-healing wireless network
Surge Protection	Class II: Overload, Short-circuit and Over-temperature protection
Operating Conditions	-20°C to +70°C ambient
Power Supply	230VAC or 115VAC, 50/60 Hz
Typical Consumption	8w typical

Fig 3.7: 'Gateway' mounted on the Pole

3.1.2 Software Architecture

4. City Manager-

City Manager (Fig 3.8) is web-based Smart City software platform for remote monitoring and management of the entire lighting infrastructure. It provides an in-depth real-time analysis and health monitoring of the assets, network and sensors. Open architecture and interface allows an easy compatibility with third-party hardware and software ensuring benefit from the investment. [6]

Fig 3.8: Web based software 'City Manager'

Dynamic Features of the software are- [6]

- Individual generation and management of dimming profiles.
- Automatic failure reports.
- Precise power usage and savings.
- Statistics and analysis of the entire lighting infrastructure.
- Different user profiles and logging of changes.

5. Scan & Go-

The Scan & Go application (Fig 3.9) is meant for the parties involved in commissioning and maintenance of Smart city solutions, namely for installation companies and system integrators. This handy tool helps installation, maintenance, and repair companies locate their devices correctly and confirm their installation to City Manager. [6]

Key features-

- In-field acquisition of device location.
- Simple and intuitive.
- Available for IOS and Android.
- App available for free in the app store with unlimited use. No license required.

Fig 3.9: Mobile application 'Scan & Go'

3.2 Technical Specification of similar products

Now we will study the products of another company apart from the ones used in our project and let us see the specifications which are common to all smart street lighting products.

3.2.1 Motion Sensor [7]

An intelligent motion sensor that automatically gets activated when a car or pedestrian is noticed in the area. If there is no activity in the area the light is optimised to a minimum lighting level. The sensor can be installed on the luminaire itself as shown in Fig 3.10 and there is no need to drill holes on the base for attachment. The technical details are provided in Table 3.6

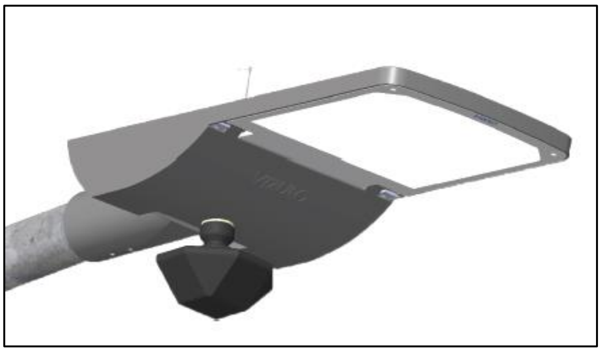


Fig 3.10: Motion Sensor mounted on the Luminaire

The sensor module consists of four sensors, two of them pointing to left and right direction and the other two pointing forward and downward direction as given in Fig 3.11.

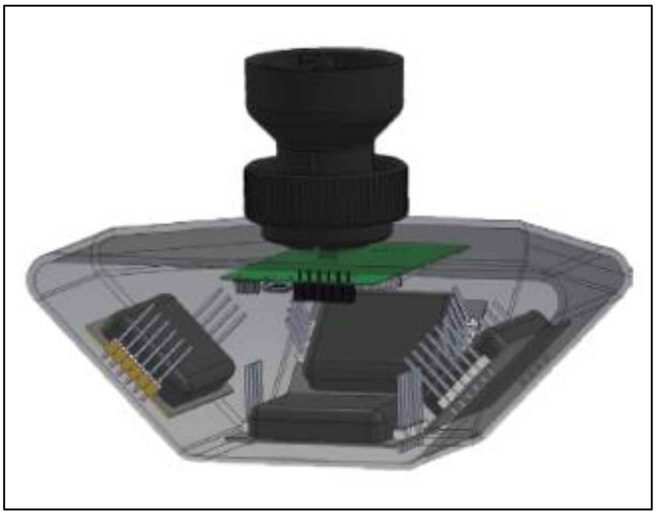


Fig 3.11: Internal details of the Sensor Module

What it does

- Detects motion and direction of the object.
- Send a communication signal to the next luminaries to brighten up or dim the light as shown in Fig 3.12.
- Additional functionality like counting cars and pedestrians.

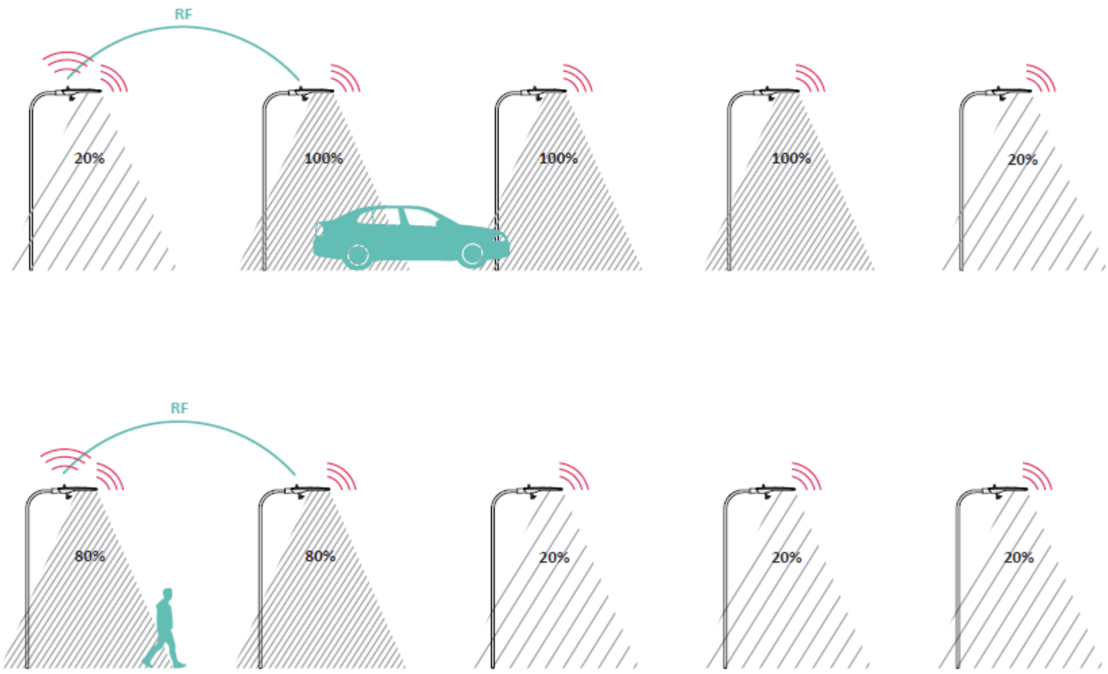


Fig 3.12: Light Intensity level adjustment according to Vehicular and Pedestrian Traffic flow

Table 3.6 Technical Details of Sensor

Parameters	Details
Tracked Data	Movement, Direction, Space
Operating Temperature	-30° to +60°C
Operating Distance	Up to 75m
Operating Angle	45° Horizontally and 38° Vertically
Protection Level	IP 66
Management	Both local and remote
Operation	Autonomous regardless of external internet network

3.2.2 Street Lighting Luminaire Controller [7]

Smart Street lighting luminaire controller (Fig 3.13) is an easily installable wireless device helping in remote management and monitoring of street light luminaires. It creates a smart, energy-efficient and safe environment. The technical details are provided in Table 3.7

Fig 3.13: 'Street Light luminaire controller'

What it does

- Provides a 2-way communication between led driver and segment controller (Fig 3.14).
- Controls and monitors street light power and dimming level.
- Measures energy and delivers data to the central monitoring system.

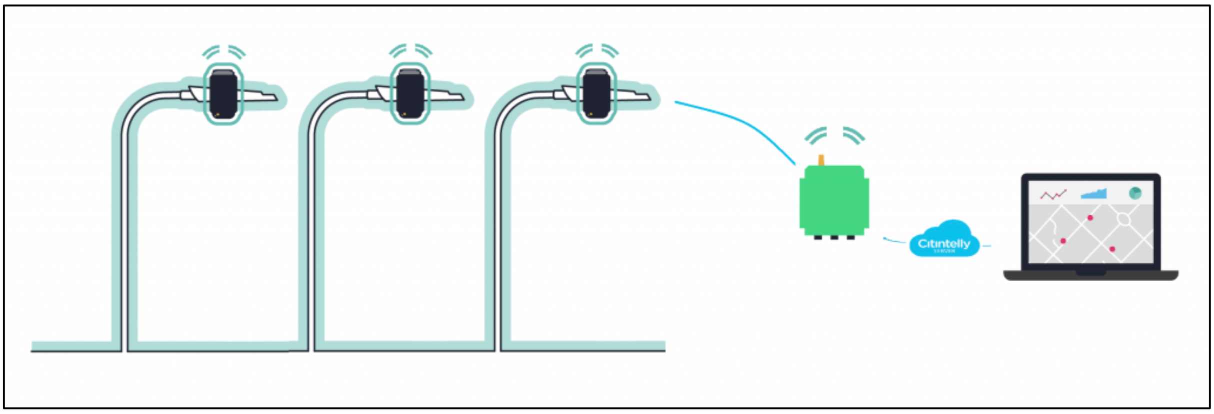


Fig 3.14: Communication between street light controller and Central Monitoring system

Table 3.7 Technical Details of luminaire controller

Parameters	Details
Supply Voltage	220-240 V
Power Supply Frequency	AC 50-60 Hz
Temperature Range	-40° to +75° C
Maximum Case Temperature	75°C
Relay Output	No-2 1 kVA each relay output
Type of Load	LED luminaire, LED/HID ballast, decorative lighting
Electrical Meter	Yes (V, I, f, cosine ϕ, P, Q, S)
LED driver control interface	DALI 18V supply/ 1-10 V
Digital Inputs	2 No's
Supply Voltage for external sensors	5V, 50 mA
RF Network connection	868 MHz, IEEE 802.15.4 standard
Dimensions	L*W*H: 105*50*40 mm
Weight	160 gm
Case Material	PA66 Flame-retardant (UL94 V0)
Conductor cross section	0.25-2.5mm^2, strip length 10-11 mm

3.2.3 Street Light Segment Controller [7]

Smart Street lighting segment controller (Fig 3.15) implements gateway function between luminaires controller and Central Management Software (CMS). It stores the configuration of the energy profiles and event reporting profiles ensuring stable operation in any circumstances. The technical details are provided in Table 3.8

Fig 3.15: Street Light Segment Controller

What it does

- Provides 2-way communication for street lights and segment controller (Fig 3.16)
- Monitors street light and cabinet.
- Stores configurations for stand-alone operating.

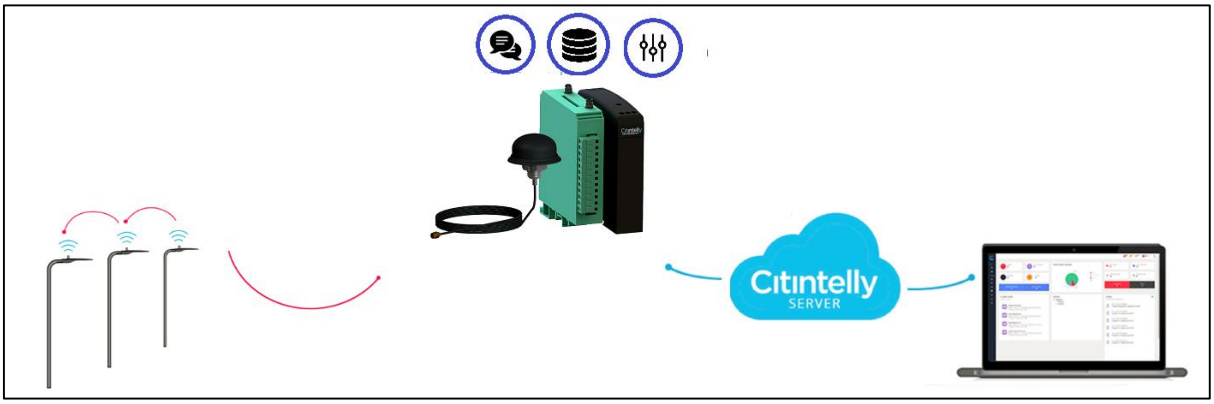


Fig 3.16: 2-way communication for street light segment controller

Table 3.8 Technical Details of segment controller

Parameters	Quantity	Details
Power Supply Type		DC or AC
Supply Voltage		AC 85-265 V / DC 19-72 V / PoE18-48 V
Temperature		-40° to +75° C
Relay Outputs	4	2A @24 VDC
Digital inputs	4	24V tolerant digital inputs
Analogue input	2	1-10 V analogue input
Analogue output	1	1-10 V analogue output
Ethernet Port	1	RJ45 connector with Power over Ethernet
GSM network Connection	1	GPRS/3G/LTE
Wi Fi/ Bluetooth connection	1	Integrated Wi Fi (IEEE 802.11 a/b/g) / Bluetooth (BR/EDR v2.1) module with built-in antenna
DALI communication	1	DALI master (10mA supply current @ 12V)
SIM slot	2	Push-pull dual micro SIM card
Memory card	1	Push-pull slot for micro SD card 4GB
Serial communication	1	RS232/ RS485
RF Network connection	1	868 MHz, IEEE 802.15.4 standard
Dimensions		W*H*D: 82*90*23 mm
Mounting		DIN rail Mounting brackets
Weight		150 gm
Enclosure Material		PA66 Flame-retardant (UL94 V0)
Conductor cross-section		0.5-1.5 mm^2, strip length 8-9 mm

3.2.4 Central Management System for Street lighting control [7]

Central Management System (CMS) as given in Fig 3.17 is a software used to manage large-scale outdoor lighting networks in order to control and monitor street lighting infrastructure while saving energy and reducing maintenance costs. This is the first step toward development of Smart City platform.

What CMS does?

- Allows to monitor and control all the luminaries remotely.
- Stores and display large quantity of historical data at one place.
- Sounds an alarm if any problem occurs.

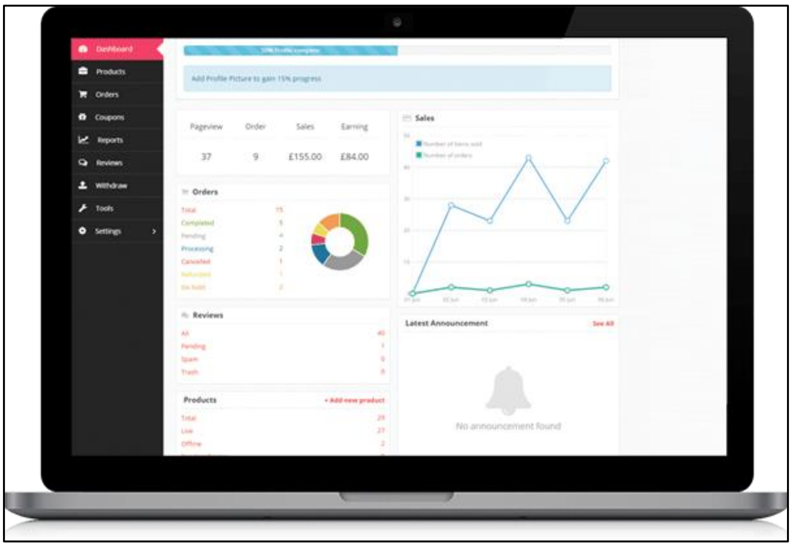


Fig 3.17: Central Management system for street lighting control

CMS features

- Luminaries on Map- View of all street lighting luminaries and street lighting controller over the map.
- Energy profiles- Create different energy profiles for different group of luminaries at different times of the day.
- Saves time- quicker potential for problem discovery and problem solving.
- Integrate with 3rd party system.

3.2.5 Surge Protector [7]

There are about 1.5 billion lightning strikes worldwide every year and a percentage of the electrical damage is caused by lightning. Public lighting system are well exposed to the environment. When there is a huge investment on smart street lighting, continuity of service is desired with least maintenance costs. This can be achieved by using a surge protector which helps to protect the luminaries from lightning and overvoltage as shown in Fig 3.18. The technical details are provided in Table 3.9

Fig 3.18: Surge Protector

What does the Surge Protector do for street lights?

The consequences of lightning damage can become evident in partial or complete failure of LED modules, damage of LED drivers, reduced brightness or failure of electrical control system. Even if the luminaire is operational, surge negatively affect its lifetime.

Table 3.9 Technical Details of Surge Protector

Parameters	Details
Voltage protection level (L-N)	1, 5 kV
V_{oc}	10 kV
I_{max}	10 kA
I_{nom}	5 kA

3.3 Design of the Project

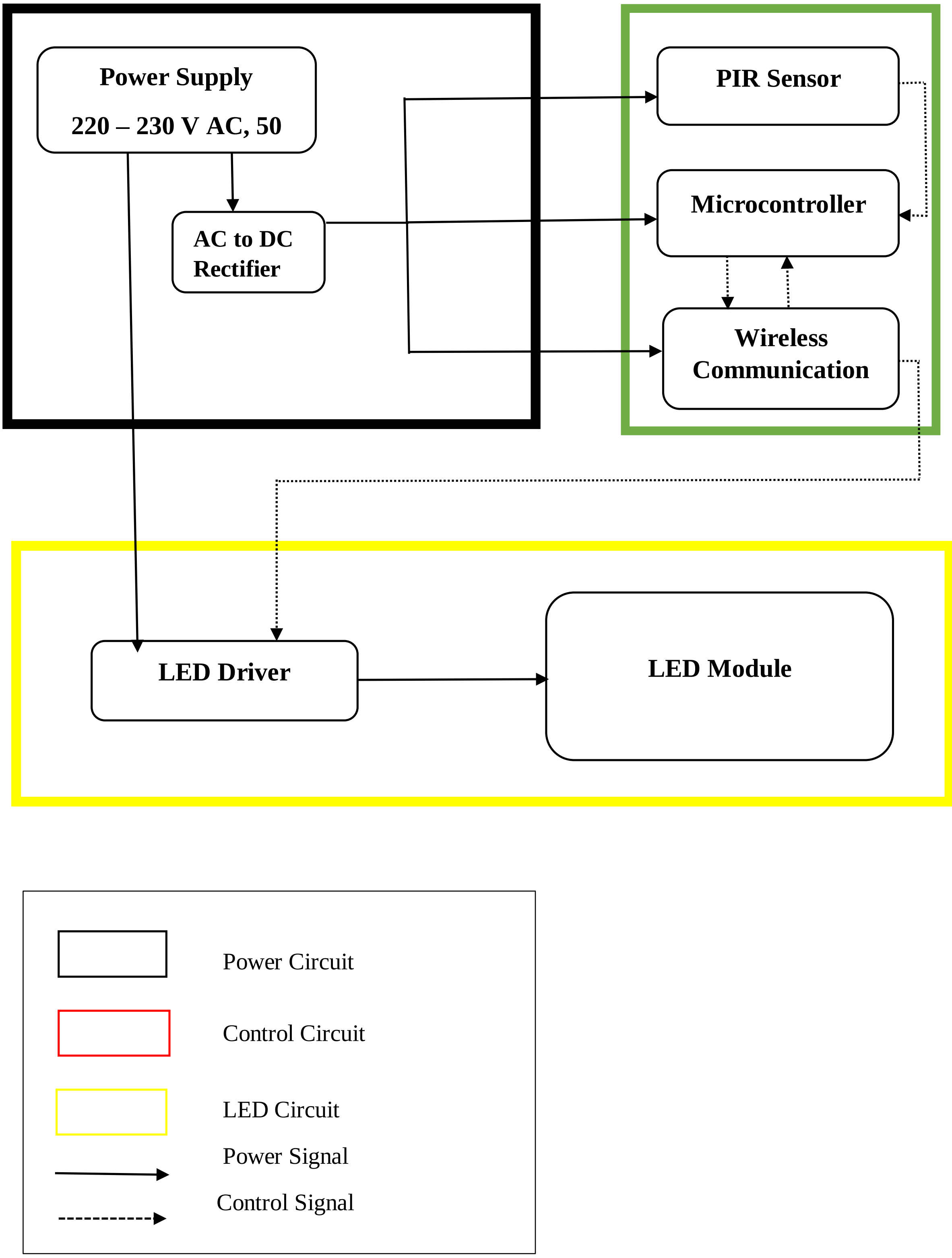


Fig 3.19: Modular overview of the System

The block diagram (Fig 3.19) consists of three blocks. The power circuit provide the necessary voltage levels required to power the modules. The Control circuit consists of the PIR sensor, Microcontroller and the communication module. The sensor will send a control signal to the microcontroller. The microcontroller will process and forward the signal to the nearby communication devices and itself provide the output to the led driver.

The LED driver is required to control the intensity of light by applying the dimming method.

3.3.1 Technical Design of Sensors

In the proposed design a motion detection sensor is required to detect cars, cyclists and pedestrians within the range of each lamp posts.

Constraint and proposal

Our system is currently designed for a club road area where the distance between the poles is nearly 15m. But now we will have to design for a major road with larger road width and the distance between poles is 25m. So now we need to have a larger range and larger viewing angle of sensors to have adequate coverage of the road.

To overcome this problem multi-sensors are used within the module. A group of 4 sensors are used to provide the total coverage of the road, one for left side of the pole, one for right side of the pole, another for bottom part of the pole and the last one for the forward path of the sensors.

The casing for the sensors also need to be resistant to all weather conditions. The Ingress Protection provided here is IP 65 which means it will protect the sensors from dust and rains.

Comparison of Sensors

Two types of sensors technology can be considered as suitable for our design proposal. Now let us have a comparison between the detailed specifications of the sensors, provided in Table 3.10

Table 3.10 Comparison of different Sensor Technologies

	PIR	Ultrasonic
Coverage	• Line of sight. • Field of view can be adjusted by the user.	• Covers entire space (volumetric). • Field of view cannot be adjusted by the user.
Highest Sensitivity	Motion lateral to the sensor.	Motion to and from the sensor.
Indoor/Outdoor Use	Indoor and outdoor.	Indoor.
Compatible Applications	• Small enclosed spaces. • Spaces where sensors has a view of the activity.	• Typically Ceiling Mounted. • Spaces with Obstacles. • Spaces with hard surfaces.

Therefore we find PIR technology to be most suitable for our applications. Although ultrasonic sensors are more sensitive and have a large coverage area, they are not considered suitable for outdoor applications.

How PIR sensor work? [8]

Passive Infrared (PIR) sensors detect infrared energy emitted by the objects. They are passive in the sense that they do not emit energy of their own, they only detect infrared. The sensors consists of two detectors configured as differential input. Whenever a warm object enters the field of one detector, there is a differential change. These change pulses are detected and interpreted as motion.

The sensor's lens defines its coverage area as a series of fan shaped zones, with small gaps in between and is most sensitive to motion that occurs between each zone. The further a person from the sensor the wider the gaps between these zones become, which decreases sensitivity proportional to the distance an can result in nuisance switching (false-off).

Position of street poles

Our design has two main position of the street poles. One is placed along the side of the road and another is placed on the central verge between the two roads. For the first case, it is possible to use one sensor module to detect both the cars and the pedestrians along the sidewalk since both are in front of the pole. For the second case we have to use two complimentary sensors pointing in opposite directions to detect motion along the road.

Position of sensors

Since the sensors are sensitive to lateral motion, it should be placed perpendicular to the poles. The sensors are placed at a height of 5m above the ground to have a sufficient coverage area.

3.3.2 Communication Network

Our primary aim in the process of designing smart street lighting system is safety and reliability. To ensure this the street lights at the current position of the car and further ahead must turn on at the right time with effective brightness. Therefore a network is required to send and receive control signals between the street lights.

Comparison of wireless technologies [10]

A wireless transmission range of at least 40m is required to ensure that the data packets are communicated successfully between two street lights. These devices must also work with low power consumption. Let us have a comparison of the various low range transmission technologies in Table 3.11

Table 3.11 Comparison among features of wireless technologies

	IEEE 802.15.4	**Bluetooth**	**Wi Fi**
Data Rate	Up to 250 Kbps	1 Mbps	11 and 54 Mbps
Range	Up to 75m	10m	50 – 100m
Topology	Peer to peer, star topology	Ad-hoc network communication topologies	Point to hub
Frequency	868 MHz (Europe), 902-928 MHz (USA), 2,4GHz (Global)	2.4 GHz	2.4 GHz and 5 GHz
Power Consumption	Low	Medium	High
Security	128 bit AES	Authorisation/ Confidentiality	Wired Equivalent policy (WEP)/ Wireless Protected Access (WPA)

From the table it can be deducted that Bluetooth is not suitable for application because of its short range. Although Wi-Fi is suitable choice in terms of data rate and security, is has extremely high power consumption. Therefore we find that wireless standard IEEE 802.15.4 with a maximum data rate of 250 Kbps is more than required and closely meets the requirements of the project.

IEEE 802.15.4 Network [9] [10]

The 802.15.4 category is probably the largest standard for low data rate wireless personal area networks (WPANs). It was developed for low data rate monitor and control applications and extended life low-power consumption uses.

The 802.15.4 standard defines the physical layer (PHY) and media access control (MAC) layer of the Open system Interconnection (OSI) model of network operation. The PHY layer defines frequency, power, modulation and other wireless conditions of the link. The MAC defines the format of data handling. The goal of the standard is to provide a base format to which other protocols and features could be added by way of the upper layers (layers 3 through 7) as shown in Fig 3.20.

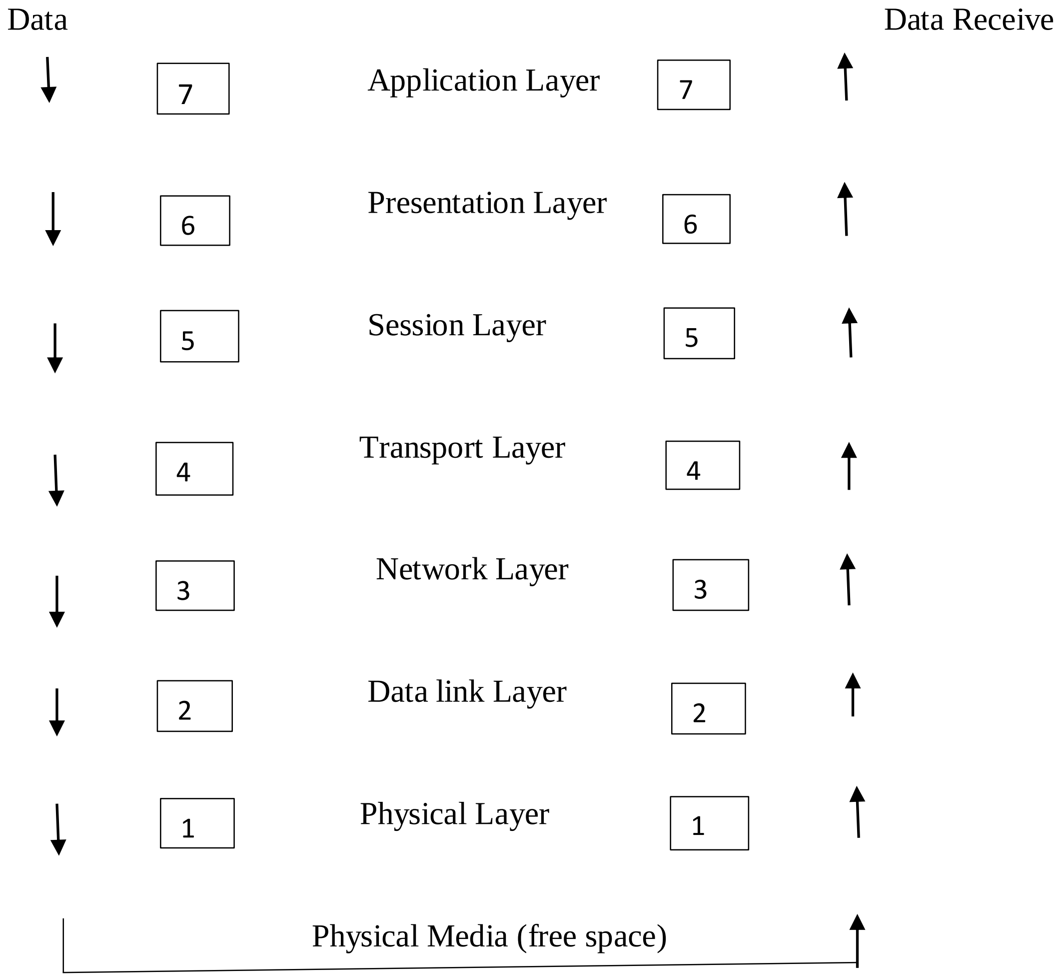


Fig 3.20: Process of Data flow in OSI Model of network operation

IEEE 802.15.4 Network Modulation formats

The standard uses direct sequence spread spectrum (DSSS) modulation. It is highly tolerant of noise and interference and offers coding again to improve link reliability.

IEEE 802.15.4 Network Topologies

There are two main forms of the network topology that can be used within IEEE 802.15.4. These network topologies may be used for different applications and offer different advantages

- Star topology: This network topology has one central node called the PAN co-ordinator with which all the other nodes communicate as shown in Fig 3.21.

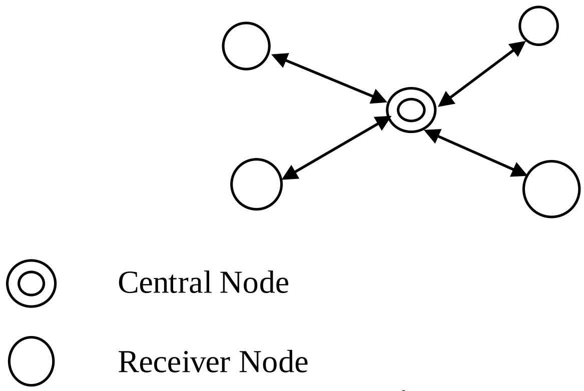


Fig 3.21: Star topology

- Peer to peer topology: In this network topology, communication may take place between different nodes and not necessarily via the co-ordinator as shown in Fig 3.22.

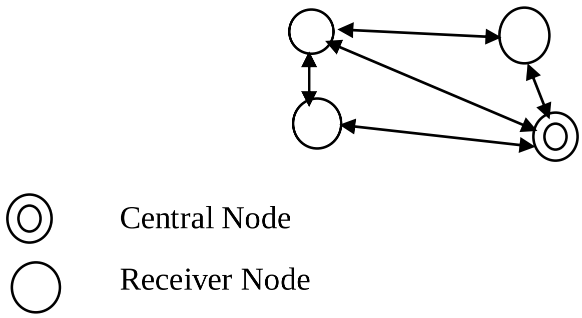
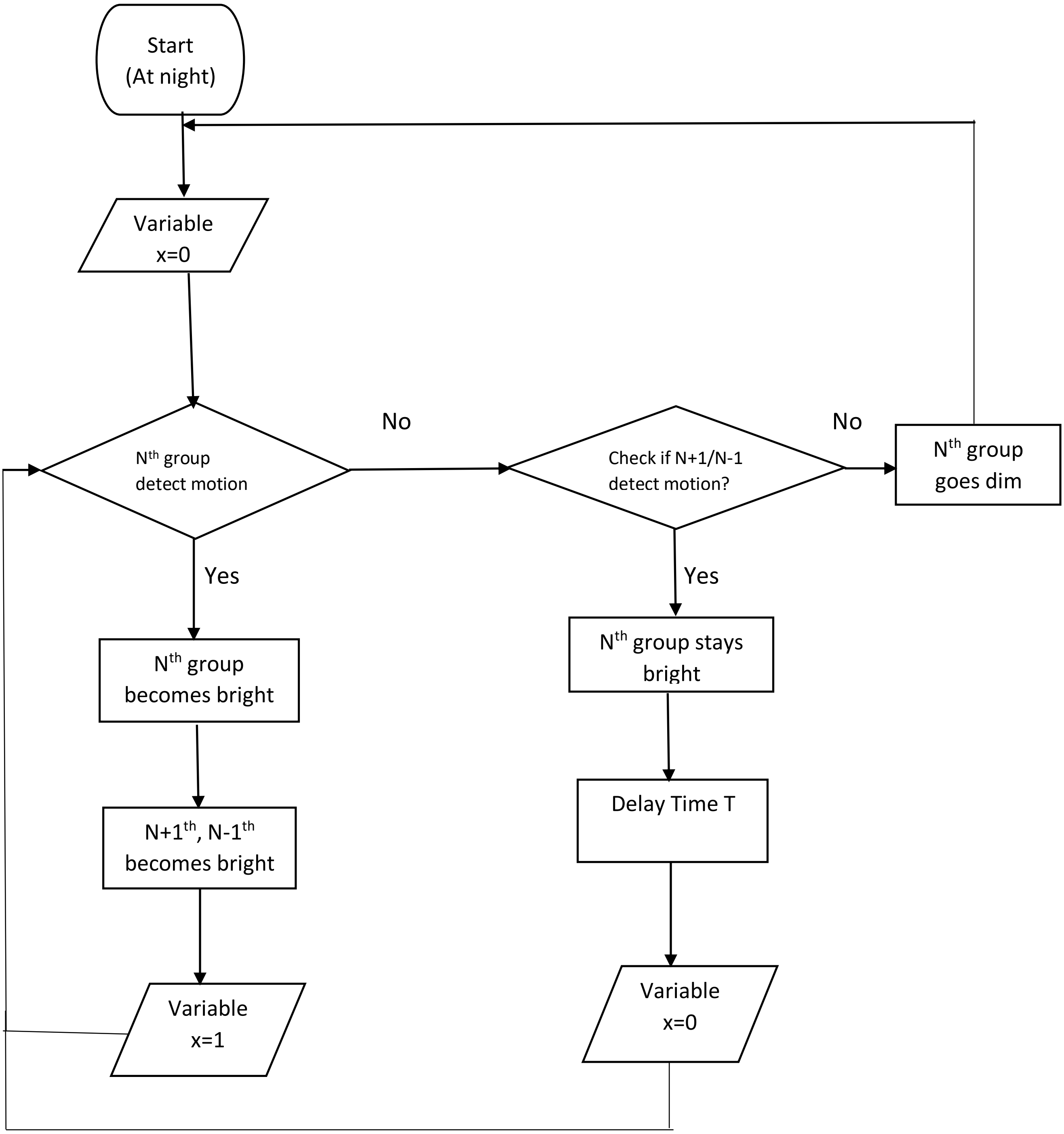


Fig 3.22: Peer to peer topology

Regarding our project, we have decided peer to peer topology to be most suitable. It has various advantages like adding/removing a device is easy, it can provide alternative route in case of a failure. Hence taking into consideration the factor of safety, an alternative route must be provided in case of failure of a device. Even it requires more overhead and routing is more complex, the positive aspects makes it a desirable one.

3.4 Flowchart illustrating the control of smart luminaries



In urban street lighting system, drivers not only need to see the road at their place but a far distance in front of them. CIE recommends that the observer need to see a span of 60m-160m in front of them. So in the case of a smart street lighting when a sensor detects a car, the sensor must respond to increase the brightness of luminaries 160m ahead of them. Therefore the algorithm for the proposed design is as follows

Let us consider a universal variable ‘x’ which represents motion detection.

- x=1 when the sensor in the Nth group detects motion and increase the brightness of the street luminaries as shown in Fig 3.23.
- x=0 when the sensor does not detect motion and the luminaries run on a dim state as shown in Fig 3.24.

When the sensor in the N^{th} group detects motion, its microcontroller sends a communication signal to the routers of nearby group and thus increasing the intensity of luminaries of those group. The intensity of the luminaries in the N^{th} group are also increased and the variable is set to 1. A delay time ‘T’ is provided to all groups which is an approximation of the maximum time taken by a pedestrian to travel between adjacent street poles. This process repeats itself if motion is detected continuously.

When the sensor in the N^{th} group does not detect motion, we need to check whether the sensors in the adjacent groups detects motion. If the adjacent sensors detects motion that means the car is moving alongside the N+1 or N-1 group. Therefore the luminaries in the adjacent group should be kept at its maximum intensity for a period of time. Now the variable x is set to 0.

Else we consider that there are no moving cars in the path and the luminaries in the N^{th} group should go to a dim state.

Fig 3.23: Luminaires on a dim state at the club road

Fig 3.24: Luminaires on maximum intensity at the club road

3.5 Benefits of Smart Street Lighting solution [6]

1. Brand your city with intelligence

   - Adaptive Lighting
   - Remote monitoring and management
   - Advanced ‘Smart City’ function possibilities, easily upgrade your city in the future
   - Increased city attractiveness through better safety and security

2. Make the best of your investment

   - Reduced energy and maintenance costs
   - Energy Consumption Analytics
   - Increased lifetime of lighting fixtures

3. Taking responsibility of our environment

   - Energy savings and CO_2 emission reduction
   - Reduced light pollution
   - Ecosystem protection

4. City beautification

   - Increased sense of safety and security
   - Attractive, pleasant and inviting atmosphere
   - Custom ambience of festivals and events

5. Lighting Control

   - Full control over lighting infrastructure
   - Switching & dimming individual and group wise luminaires
   - Based on time, astronomical clock events
   - Adaptable for special city events
   - Adaptable during street construction works
   - ‘Emergency mode’ enables quick lighting control in case of calamity

6. System Monitoring

   - Collecting data from the system
   - Failure identification
   - Sensor information

7. Maintenance Cost saving

   - No night patrols required
   - Exact failure knowledge

CHAPTER- 4

COST BENEFIT ANALYSIS OF SMART STREET LIGHTING SYSTEM

4.1 Comparison between conventional and Smart Street lighting system

Project Definition

"Providing Smart Street Lighting arrangement on the central median and service road of Biswa Bangla Sarani at Newtown, Kolkata under WBHIDCO"

A retrofitting project providing smart solutions and moving a step forward towards development of Smart City. The road lighting project is based on Action Area II of Newtown region, Kolkata over two roads named as 'Biswa Bangla Sarani', one consisting of a central median with roads on both sides and the other one is a service road of 'Biswa Bangla Sarani'. The two roads meet at Akankha More (Fig 4.1).

The road lighting project consists of retrofitting 250W High Pressure Sodium Vapour (HPSV) luminaries with the Smart LEDs providing light only when it is needed.

Road Lighting Design Constraints-

- A total stretch of 1.8 km of road with service road of 800m and central median road extending over 1 km.
- Service road- single sided road lighting arrangement.
  Biswa Bangla Sarani- Central Verge road lighting arrangement.
- Road Width including the pavement- 8m.
- Mounting Height of Luminaries- 11m.
- Overhang- 1m (Single-sided)
  1.5m (Central Verge)
- Boom for LED luminaries- 5°
- A total of 80 poles over the entire road with 40 poles for service road and 40 poles for central median.
- Pole spacing- 20m (Service road)
  25m (Central median)

Our first objective is to calculate the wattage and the quantity of LED luminaires required to replace the conventional HPSV luminaires. A road lighting design comparison will also be made among High Pressure Sodium Vapour (HPSV), Metal Halide (MH) and LED luminaries by using the designing software DIALUX using the layout provided in Fig 4.2. We will have a cost comparison between the type of luminaries and products required for implementation of the project. Then we will make an energy comparison and calculate the percentage of energy savings estimated after commissioning the project.

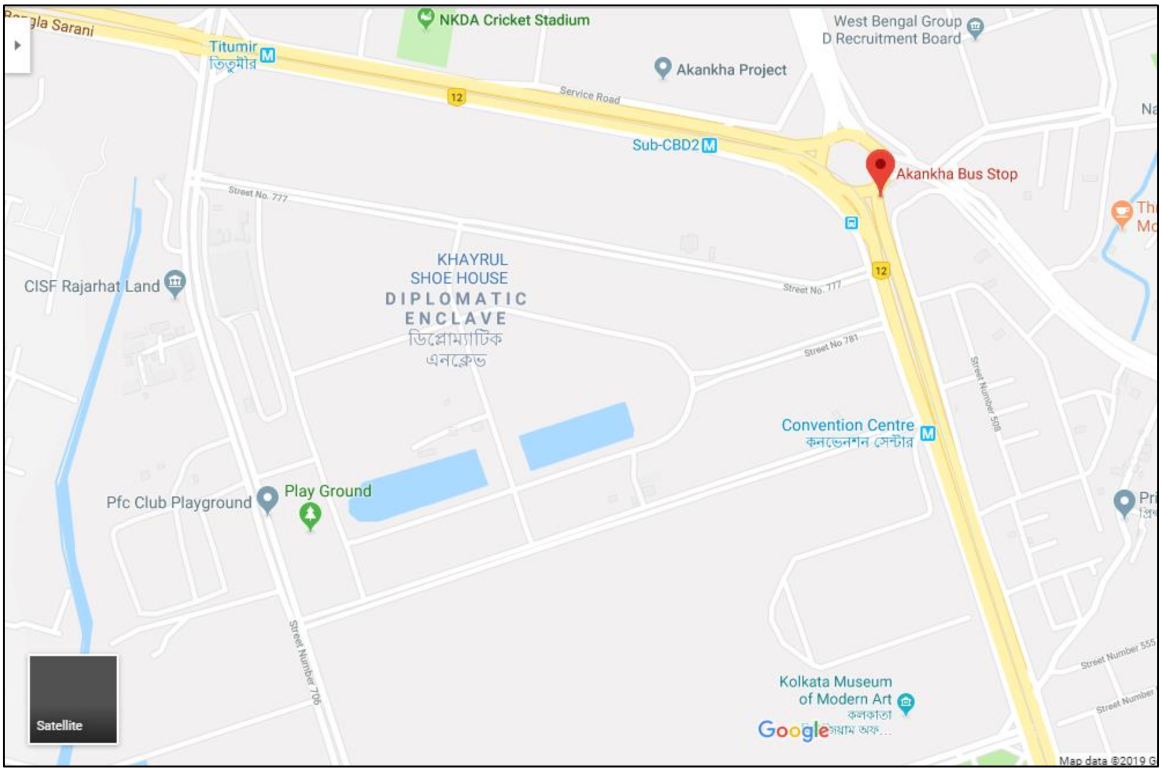


Fig 4.1A: View of the road in Google Map for road lighting design

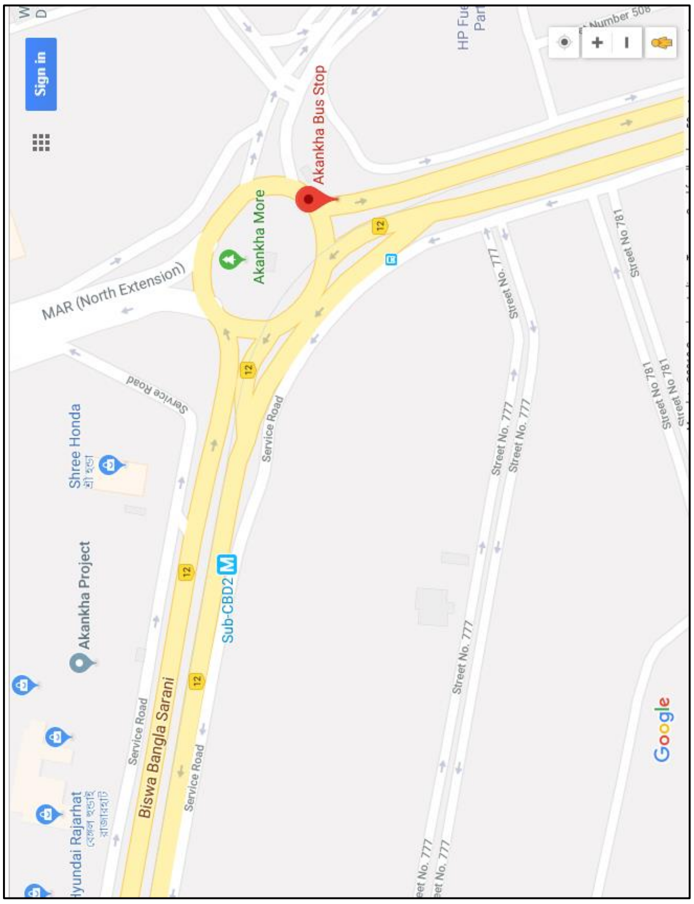


Fig 4.1B: View of the road in Google Map for road lighting design

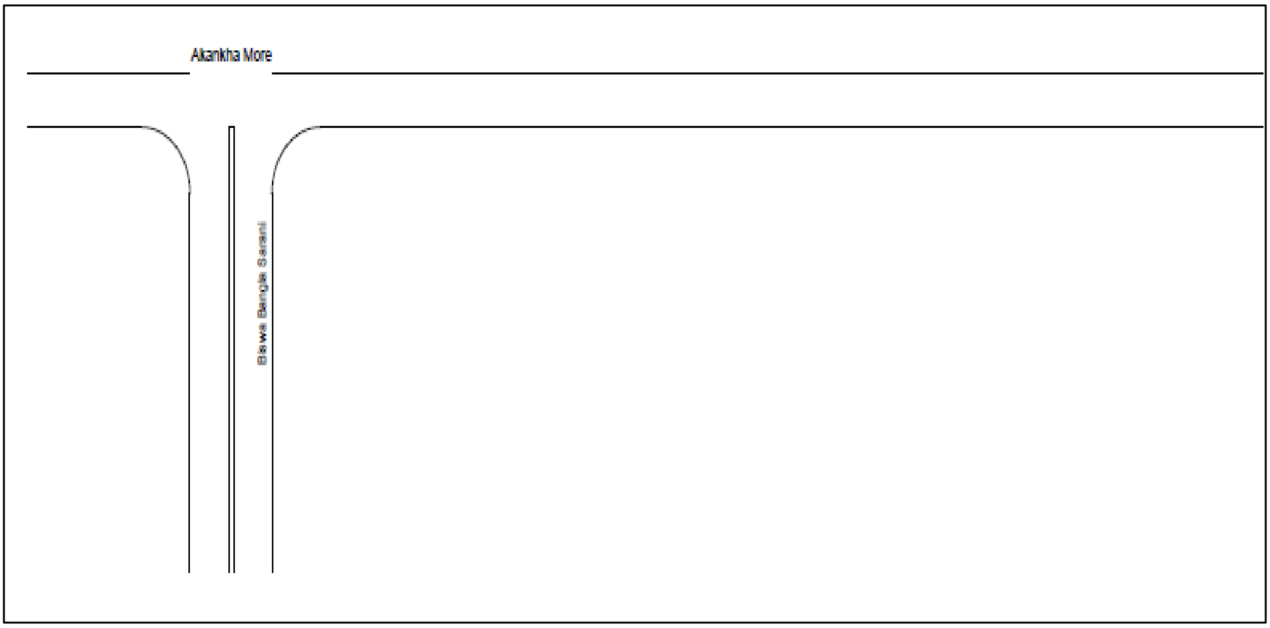


Fig 4.2A: Layout of the road for designing in DIALUX

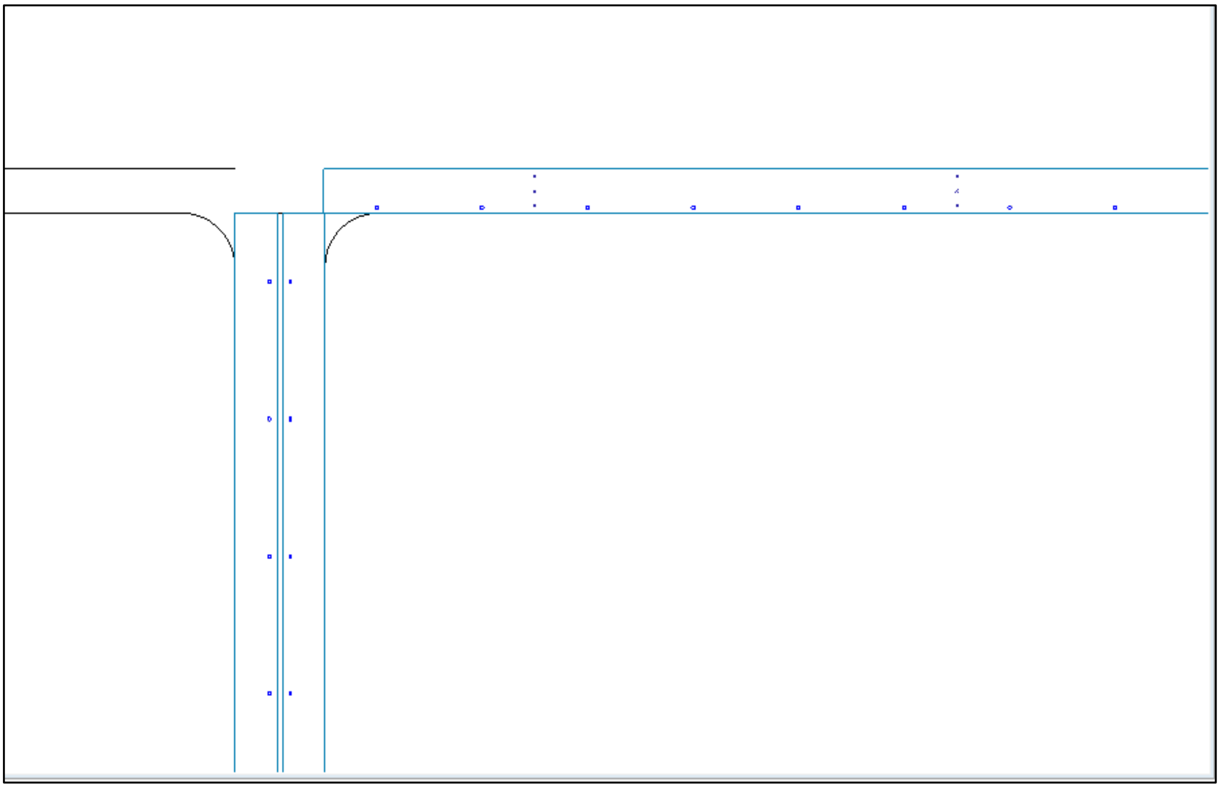


Fig 4.2B: Layout of the road for designing in DIALUX

4.1.1 Roadway Lighting Luminaire Specifications

1. **BGEST 250 SV/MH IP 66 LH MOM.WOB** (BAJAJ 250W HPSV/MH roadway luminaire as shown in Fig 4.3) [11]

- Die-cast aluminium housing with EPDM gasket for lamp and control gear accessories.
- Electrochemically brightened, polished and anodised aluminium reflector.
- Degree of Protection: IP 66.
- Nominal voltage: 220/240 V.
- Mains current in amps at 240 V: 1.3A
- Capacitor: 30 mfd
- Power factor: > 0.85

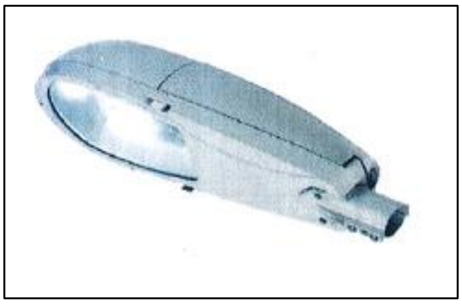


Fig 4.3: BGEST 250 SV/MH IP 66 LH MOM.WOB

2. **BRTFG 140W LED** (BAJAJ 140W LED luminaire as shown in Fig 4.4) [12]

- Pressure die-cast housing with toughened glass.
- Secondary optics for better light distribution.
- Driver protection against lightning, overvoltage and short-circuit.
- Top open able access to driver from top.
- Rated supply voltage- 140-280VAC
- Efficacy- ~100 lm/W
- CCT- 5700 +/- 300K
- CRI- ~70
- Level of protection- IP 66
- IK 07
- Power factor- 0.95
- THD- <10 %

Fig 4.4: BRTFG 140W LED

4.1.2 Road Lighting Design using DIALUX and calculation of UPD

1. **Illuminance based road lighting design by HPSV luminaires**

DIALUX report on designing of Service Road by HPSV luminaires

E_{av} (lux)	E_{min} (lux)	E_{max} (lux)	U0	E_{min}/E_{max}
27	23	31	0.833	0.729

DIALUX report in designing of Central Road 1 by HPSV luminaires

E_{av} (lux)	E_{min} (lux)	E_{max} (lux)	U0	E_{min}/E_{max}
39	20	52	0.522	0.393

DIALUX report in designing of Central Road 2 by HPSV luminaires

E_{av} (lux)	E_{min} (lux)	E_{max} (lux)	U0	E_{min}/E_{max}
39	20	52	0.522	0.393

2. **Illuminance based road lighting design by MH luminaires**

DIALUX report on designing of Service Road by HPSV luminaires

E_{av} (lux)	E_{min} (lux)	E_{max} (lux)	U0	E_{min}/E_{max}
32	24	36	0.757	0.666

DIALUX report in designing of Central Road 1 by MH luminaires

E_{av} (lux)	E_{min} (lux)	E_{max} (lux)	U0	E_{min}/E_{max}
37	25	48	0.681	0.530

DIALUX report in designing of Central Road 2 by MH luminaires

E_{av} (lux)	E_{min} (lux)	E_{max} (lux)	U0	E_{min}/E_{max}
37	25	48	0.681	0.530

3. **Illuminance based road lighting design by LED luminaires**

DIALUX report on designing of Service Road by HPSV luminaires

E_{av} (lux)	E_{min} (lux)	E_{max} (lux)	U0	E_{min}/E_{max}
29	25	33	0.846	0.746

DIALUX report in designing of Central Road 1 by LED luminaires

E_{av} (lux)	E_{min} (lux)	E_{max} (lux)	U0	E_{min}/E_{max}
34	30	36	0.893	0.838

DIALUX report in designing of Central Road 2 by LED luminaires

E_{av} (lux)	E_{min} (lux)	E_{max} (lux)	U0	E_{min}/E_{max}
34	30	36	0.893	0.838

1. **Calculation of UPD for HPSV/MH luminaires**
   a. Service Road

UPD= no of luminaries per cycle* Wattage/luminaire*1.15/ (Span*Width)

= 1*284*1.15/ (20*8)

= 2.04 W/m^2

b. Biswa Bangla Sarani

UPD= no of luminaries per cycle* Wattage/luminaire*1.15/ (Span*Width)

= 1*284*1.15/ (25*8)

= 1.63 W/m^2

2. **Calculation of UPD for LED luminaries**
   i. Service Road

UPD= no of luminaries per cycle* Wattage/luminaire*1.15/ (Span*Width)

= 1*140*1.15* (20*8)

= 1.00625 W/m^2

ii. Biswa Bangla Sarani

UPD= no of luminaries per cycle* Wattage/luminaire*1.15/ (Span*Width)

= 1*140*1.15* (25*8) =0.805 W/m^2

4.1.3 Cost Comparison of two Projects

1. Conventional Street Lighting Project using HPSV/MH luminaries

   A total number of 80 poles were installed during commissioning of the project.
   Total number of luminaries for single sided arrangement= 40
   Total number of luminaries for central verge arrangement= 80

   Thus, total number of luminaries for the entire project= 120

BOQ for conventional HPSV Lighting Project				
Items required	**Quantity**	**M.R.P**	**Cost/unit (Rs)**	**Total price (Rs)**
BGEST 250 SV IP 66 LH Complete	120	15140	7570	908400

BOQ for conventional MH Lighting Project				
Items required	**Quantity**	**M.R.P**	**Cost/unit (Rs)**	**Total price (Rs)**
BGEST 250 MH IP 66 LH Complete	120	15170	7585	910200

2. Smart Street Lighting Project

   The items required for the implementation of the Smart Lighting Project are

   - Sensors
   - LED street light luminaire
   - LED street light luminaire controller
   - Gateway

Selection of Sensors, Controllers & Gateway

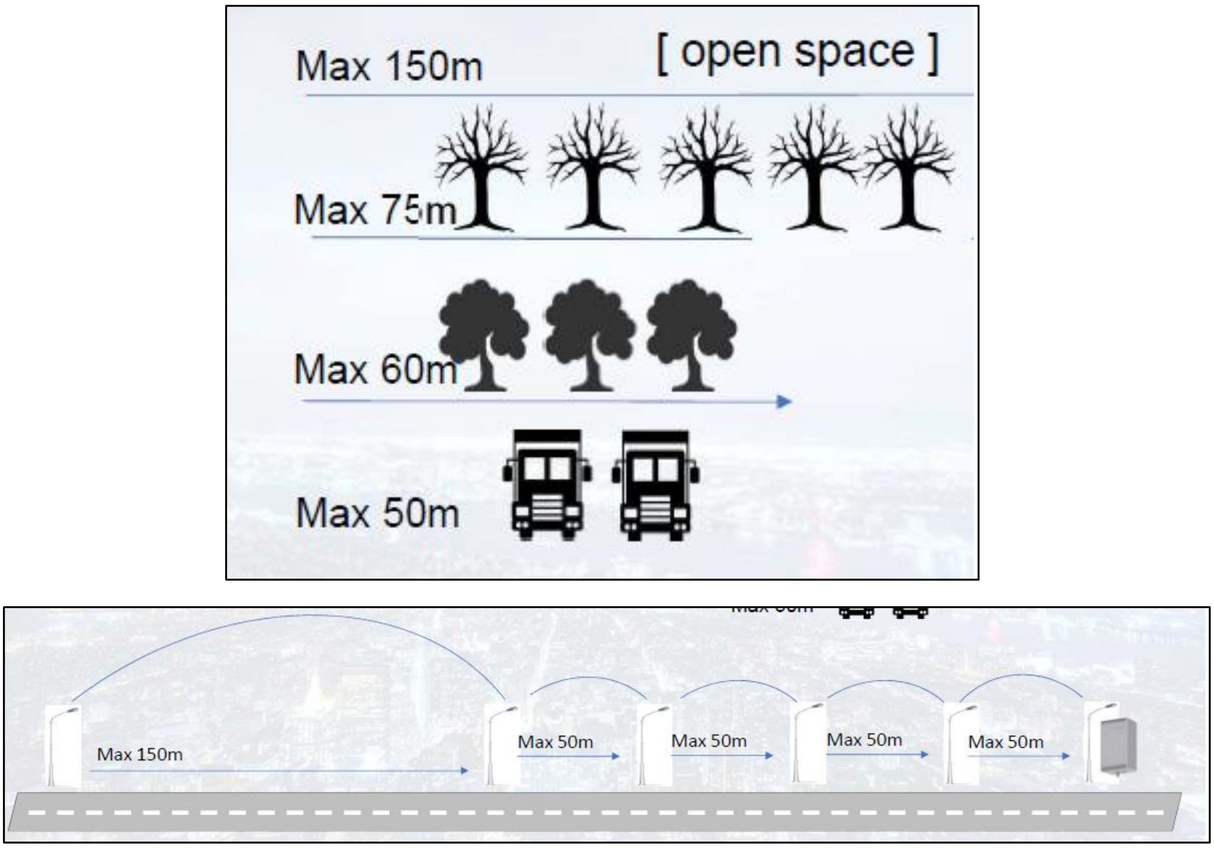


Fig 4.5: Maximum range of sensors with various constraints

The sensors uses IEEE 802.15.4 standard to communicate over the air. From the figure we can say that the sensors can communicate with each other for a maximum distance of 150m without any interruption. In case of big trees, the distance is limited to 60m and in case of small tress, it is limited to 75m. With the presence of truck/ bus bays by the side of road this distance is limited to 50m as given in Fig 4.5.

In our project, some shrubs are present by the side of the road or on the central median which do not interrupt the communication between sensors. For creating a dense network we consider a distance of 100m between each sensor.

Therefore the total number of sensors required for the entire project is 24.

The poles where sensors are installed, there is no need to install luminaire controller again as it present in conjunction with the sensor module.

Thus the total number of LED luminaries without lighting controller is 24 and the total no of LED luminaire with lighting controller is (120-24) or 96.

According to the specification of the company, the maximum Node: Gateway ratio is 1: 200. For our project the number of luminaire to Gateway ratio is 1: 120. So, number of Gateway required is 1.

BOQ for Smart Lighting Project				
Items required	**Quantity**	**M.R.P**	**Cost/Unit**	**Total Price (Rs)**
140W LED luminaire without lighting controller	24	20000	10000	240000
140W LED luminaire with lighting controller	96	37000	18500	1776000
Sensor	24	30000	15000	360000
Gateway	1	140000	140000	140000
				2516000

4.1.4 Energy Comparison and calculation of Energy Savings

1. **Total Annual Energy Consumption of entire HPSV/MH luminaries used in the project**

Wattage of each HPSV/MH luminaire= 250W
Ballast loss for each luminaire= 34W
Total operating hours of luminaire in a day= 12 hours

Total Energy consumption of a luminaire in a day= (250+34)*12 W-hour
= 284*12 W-hour
= 3408 W-hour
Total energy consumption of 120 luminaires in a day= 120*3408 W-hour
= 408960 W-hour or 408.96 kWh

Total annual energy consumption of 120 luminaries= 408.96*365 kWh
= 149270.4 kWh

2. **Total Annual Energy consumption of LED luminaries used in the Smart Lighting Project**

Since the actual project is still not completed and is under process, we cannot get the real energy usage data. We can get the amount of the operating hours of the luminaries used in the demo project for a small residential road and calculate the energy usage for the demo project. Later we can analyse this data to calculate the energy consumption of the real project. Total operating hours of a Smart luminaire for a weekday and Sunday is provided in Table 4.1 and 4.2 respectively. The dimming profiles used in the Demo project and chosen for main project are provided in Table 4.3, 4.4, 4.5 respectively.

Table 4.1 Total operating hours of a luminaire used in the demo project for a weekday

Initial Time for Counting	Total time for which intensity of lamp is 80%	Total time for which intensity of lamp is 10%	Total time for which intensity of lamp is 100%	Total time for which intensity of lamp is 20%	Time Slot
00:10:00	00:09:56	00:05:04			00:15:00
00:25:00	00:05:21	00:09:39			00:15:00
00:40:00	00:06:45	00:08:14			00:15:00
00:55:00	00:02:53	00:12:07			00:15:00
01:10:00	00:04:29	00:10:32			00:15:00
01:25:00	00:03:06	00:11:54			00:15:00
01:40:00	00:02:39	00:12:21			00:15:00
01:55:00	00:05:21	00:09:39			00:15:00
02:10:00	00:00:44	00:14:16			00:15:00
02:25:00	00:02:05	00:12:55			00:15:00
02:40:00	00:02:20	00:12:40			00:15:00
02:55:00	00:00:00	00:15:00			00:15:00
03:10:00	00:00:22	00:14:38			00:15:00
03:25:00	00:01:59	00:13:01			00:15:00
03:40:00	00:00:22	00:14:38			00:15:00
03:55:00	00:00:00	00:15:00			00:15:00
04:10:00	00:00:26	00:14:34			00:15:00
04:25:00	00:00:48	00:14:12			00:15:00
04:40:00	00:00:44	00:14:16			00:15:00
04:55:00	00:00:22	00:04:38			00:05:00
17:00:00			00:00:00	00:11:00	00:11:00
17:11:00			00:01:16	00:13:44	00:15:00
17:26:00			00:14:54	00:00:06	00:15:00
17:41:00			00:15:00	00:00:00	00:15:00
17:56:00			00:15:00	00:00:00	00:15:00
18:11:00			00:15:00	00:00:00	00:15:00
18:26:00			00:15:00	00:00:00	00:15:00
18:41:00			00:15:00	00:00:00	00:15:00
18:56:00			00:15:00	00:00:00	00:15:00
19:11:00			00:15:00	00:00:00	00:15:00
19:26:00			00:14:52	00:00:08	00:15:00
19:41:00			00:14:52	00:00:08	00:15:00
19:56:00			00:14:58	00:00:02	00:15:00
20:11:00			00:14:45	00:00:15	00:15:00
20:26:00			00:14:53	00:00:07	00:15:00
20:41:00			00:14:51	00:00:09	00:15:00
20:56:00			00:15:00	00:00:00	00:15:00
21:11:00			00:14:53	00:00:07	00:15:00
21:26:00			00:14:40	00:00:20	00:15:00

21:41:00			00:14:53	00:00:07	00:15:00
21:56:00			00:13:12	00:01:48	00:15:00
22:11:00			00:11:56	00:03:04	00:15:00
22:26:00			00:09:44	00:05:16	00:15:00
22:41:00			00:08:16	00:06:44	00:15:00
22:56:00			00:11:52	00:03:08	00:15:00
23:11:00	00:06:59	00:04:05	00:02:42	00:01:14	00:15:00
23:26:00	00:06:20	00:08:40			00:15:00
23:41:00	00:09:02	00:05:58			00:15:00
23:56:00	00:09:13	00:04:47			00:14:00
	01:22:16	**04:22:48**	**5:27:29**	**00:47:27**	**12:00:00**

Table 4.2 Total operating hours used in the demo project for a Sunday

Initial Time for Counting	Total time for which intensity of lamp is 80%	Total time for which intensity of lamp is 10%	Total time for which intensity of lamp is 100%	Total time for which intensity of lamp is 20%	Time Slot
00:10:00	00:14:18	00:00:42			00:15:00
00:25:00	00:13:38	00:01:22			00:15:00
00:40:00	00:14:10	00:00:50			00:15:00
00:55:00	00:13:45	00:01:15			00:15:00
01:10:00	00:12:11	00:02:49			00:15:00
01:25:00	00:10:49	00:04:11			00:15:00
01:40:00	00:12:13	00:02:47			00:15:00
01:55:00	00:14:04	00:00:56			00:15:00
02:10:00	00:13:08	00:01:52			00:15:00
02:25:00	00:12:52	00:02:08			00:15:00
02:40:00	00:14:34	00:00:26			00:15:00
02:55:00	00:13:41	00:01:19			00:15:00
03:10:00	00:13:45	00:01:15			00:15:00
03:25:00	00:11:18	00:03:42			00:15:00
03:40:00	00:10:27	00:04:33			00:15:00
03:55:00	00:11:12	00:03:48			00:15:00
04:10:00	00:12:22	00:02:38			00:15:00
04:25:00	00:10:41	00:04:19			00:15:00
04:40:00	00:14:28	00:00:32			00:15:00
04:55:00	00:04:04	00:00:56			00:05:00
17:00:00				00:10:00	00:10:00
17:10:00				00:15:00	00:15:00
17:25:00			00:15:00		00:15:00
17:40:00			00:15:00		00:15:00
17:55:00			00:15:00		00:15:00
18:10:00			00:15:00		00:15:00

18:25:00			00:15:00		00:15:00
18:40:00			00:15:00		00:15:00
18:55:00			00:15:00		00:15:00
19:10:00			00:15:00		00:15:00
19:25:00			00:15:00		00:15:00
19:40:00			00:15:00		00:15:00
19:55:00			00:16:00		00:16:00
20:11:00			00:15:00		00:15:00
20:26:00			00:15:00		00:15:00
20:41:00			00:15:00		00:15:00
20:56:00			00:15:00		00:15:00
21:11:00			00:14:43	00:00:17	00:15:00
21:26:00			00:14:51	00:00:09	00:15:00
21:41:00			00:14:52	00:00:08	00:15:00
21:56:00			00:14:30	00:00:30	00:15:00
22:11:00			00:13:50	00:01:10	00:15:00
22:26:00			00:14:45	00:00:15	00:15:00
22:41:00			00:14:24	00:00:36	00:15:00
22:56:00			00:13:52	00:01:08	00:15:00
23:11:00	00:10:56	00:00:13	00:03:31	00:00:20	00:15:00
23:26:00	00:13:12	00:01:48			00:15:00
23:41:00	00:14:20	00:00:40			00:15:00
23:56:00	00:12:36	00:01:24			00:14:00
	4:58:44	**0:46:25**	**5:45:18**	**0:29:33**	**12:00:00**

Table 4.3 Dimming profiles for Demo project in a weekday & Sunday

Timing	**Dimming %**
05:00 p.m. to 11:00 p.m.	When motion is detected- 100% Absence of motion- 20%
11:00 p.m. to 05:00 a.m.	When motion is detected- 80% Absence of motion- 10%

Table 4.4 Dimming profiles chosen for the real project in a weekday

Timing	**Dimming %**
05:00 p.m. to 11:00 p.m.	When motion is detected- 100% Absence of motion- 60%
11:00 p.m. to 05:00 a.m.	When motion is detected- 80% Absence of motion- 30%

Table 4.5 Dimming profiles chosen for the real project in a Sunday

Timing	Dimming %
05:00 p.m. to 11:00 p.m.	When motion is detected- 100% Absence of motion- 30%
11:00 p.m. to 05:00 a.m.	When motion is detected- 80% Absence of motion- 30%

Let us now analyse these dimming profiles to calculate the energy consumption of Smart LED luminaires

Total energy consumption of 140W LED luminaire with intensity of lamp being 80% in a weekday= (1+22/60+16/3600)*140*0.8 W-hour

= 1.3710*140*0.8 W-hour

= 41.56 W-hour

Total energy consumption of 140W LED luminaire with intensity of lamp being 30% in a weekday= (4+22/60+28/3600)*140*0.3 W-hour

= 4.3743*140*0.3 W-hour

= 183.72 W-hour

Total energy consumption of 140W LED luminaire with intensity of lamp being 100% in a weekday= (5+27/60+29/3600)*140 W-hour

= 5.458*140 W-hour

= 764.12 W-hour

Total energy consumption of 140W LED luminaire with intensity of lamp being 60% in a weekday= (47/60+27/3600)*140*0.6 W-hour

= 0.7908*140*0.6 W-hour

= 66.42 W-hour

Total energy consumption of a LED luminaire in a weekday

= (41.56+183.72+764.12+66.42) W-hour

= 1055.82 W-hour

Total energy consumption of 120 LED luminaire in a weekday

= 1055.82*120 kWh

= 126.7 kWh

Total energy consumption of 140W LED luminaire with intensity of lamp being 80% in a Sunday= (4+58/60+44/3600)*140*0.8 W-hour

= 4.9788*140*0.8 W-hour

= 557.63 W-hour

Total energy consumption of 140W LED luminaire with intensity of lamp being 30% in a Sunday= (46/60+25/3600)*140*0.3 W-hour

= 0.7735*140*0.3 W-hour

= 32.48 W-hour

Total energy consumption of 140W LED luminaire with intensity of lamp being 100% in a Sunday= (5+45/60+18/3600)*140 W-hour

= 5.755*140 W-hour

= 805.7 W-hour

Total energy consumption of 140W LED luminaire with intensity of lamp being 30% in a Sunday= (29/60+33/3600)*140*0.3 W-hour

= 0.4927*140*0.3 W-hour

= 20.69 W-hour

Total energy consumption of a LED luminaire in a Sunday

= (557.63+32.48+805.7+20.69) W-hour

= 1416.5 W-hour

Total energy consumption of 120 LED luminaires in a Sunday

= 1416.5*120 kWh

= 169.98 kWh

Total energy consumption of 120 Smart LED in a complete week

= (126.7*6+169.98) kWh

= 930.18 kWh

Total annual energy consumption of 120 Smart LED

= (930.18*52+126.7) kWh

= 48496.06 kWh

Total annual energy savings for up gradation of the project

= (149270.4-48496.06) kWh or 100774.34 kWh

% of Energy savings= (100774.34/1492370.4)*100

=67.5%

4.1.5 Calculation of Simple Payback Period and the cost saved due to smart application

	Conventional Lighting		Smart Lighting
Parameters			
No of lamps	120	120	120
Luminaire	HPSV	MH	LED
Lamp Wattage (W)	250	250	140
Ballast loss (W)	34	34	0
Operating hours	12	12	12
Energy Consumed/weekday (kWh)	408.96	408.96	126.7
Energy Consumed/Sunday (kWh)	408.96	408.96	169.96
Energy consumed/week (kWh)	2862.72	2862.72	930.16
Energy consumed/year (kWh)	149270.4	149270.4	48495.02
Energy Saving/year (kWh)			100775.38
% of Energy Saving			67.51
Cost of Electricity/unit (Rs)			6.64
Energy Cost Saving/year (Rs)			669148.5232
Cost/ Lamp (Rs)	412.50	510.00	Nil
Average economic life / lamp (hrs.)	10,000	7,500	50,000
Number of Lamps replacement/ year	48	70	0
Cost of Lamp replacement/ year (Rs)	19800	35700	0
Cost/ Ballast and ignitor (Rs)	3150	3150	0
Number of ballast and ignitor replacement/ year (assuming 20% failure)	24	24	0
Cost of ballast and ignitor replacement (Rs)	75600	75600	0
Total Cost saving/ year considering retrofitting of HPSV with Smart LED (Rs)			764548.5232
Total Cost saving/ year considering retrofitting of MH with Smart LED (Rs)			780448.5232
Total Initial Cost for installation (Rs)	908400	910200	2516000
Total Extra investment due HPSV luminaries (Rs)			1607600
Total Extra investment due MH luminaries (Rs)			1605800

Simple Payback Period due HPSV luminaries (Years)			2.1
Simple Payback Period due MH luminaries (Years)			2.06

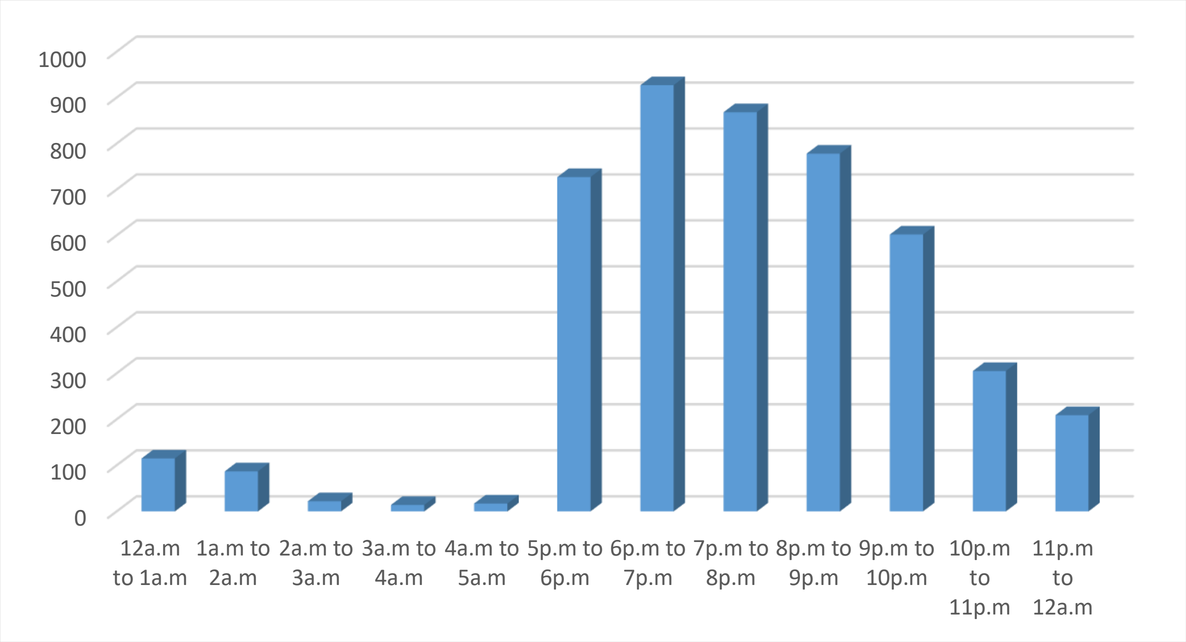


Fig 4.6: Hourly Triggers of a Sensor Module for a weekday

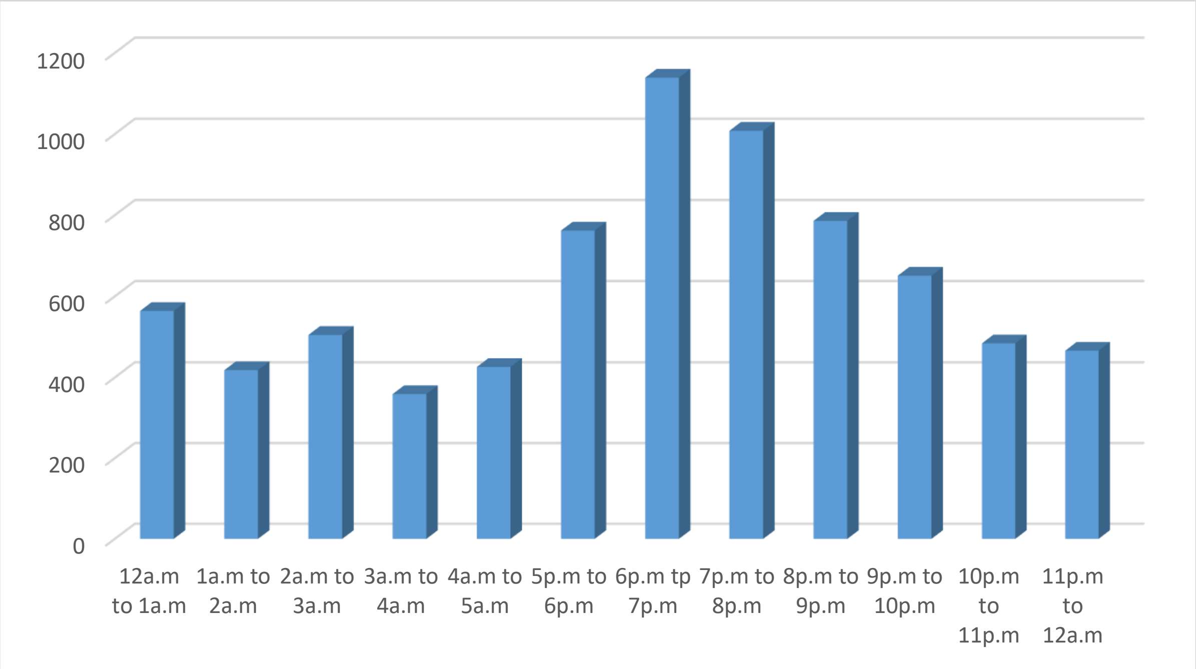


Fig 4.7: Hourly Triggers of a Sensor Module for a Sunday

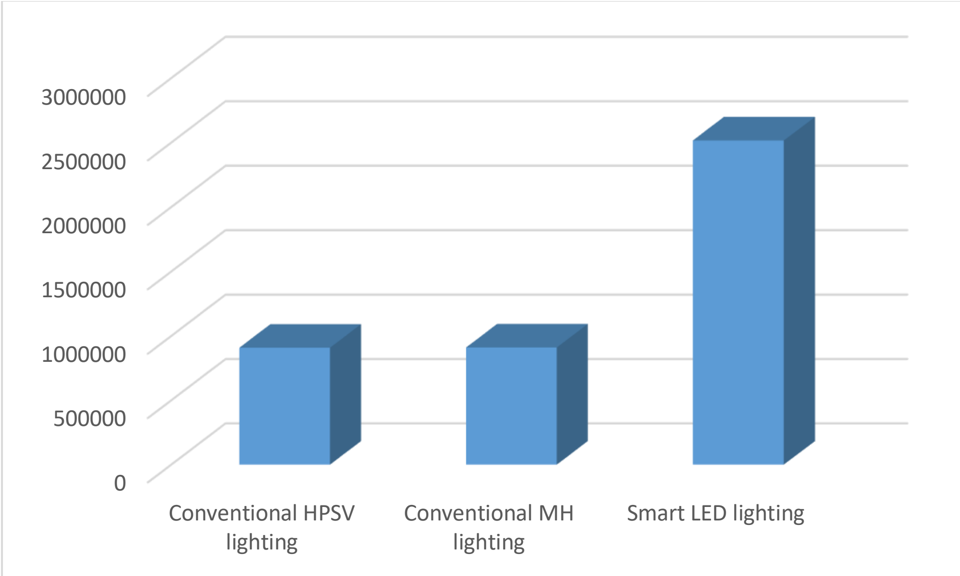


Fig 4.8: Comparison among total Cost for Installation

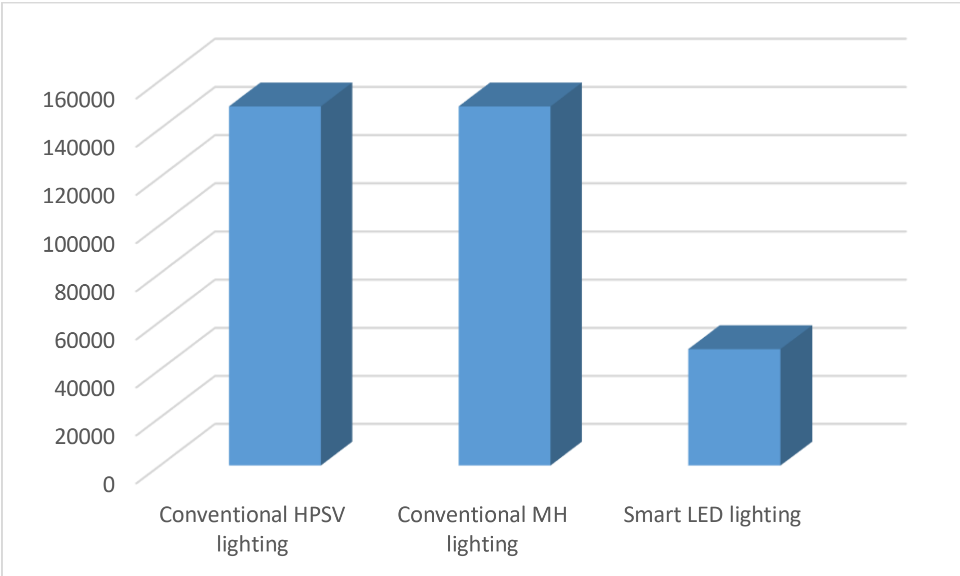


Fig 4.9: Comparison among Energy Consumed/ Year (kWh)

4.2 Limitations of Smart street lighting system [13] [14]

It has been noticed that the power quality of a LED luminaire is hampered by applying various dimming profiles. Commonly used LED drivers are designed to high performance at the rated output voltage and rated forward current. If this is not the case such as in the case of dimming, increased emissions of current harmonics and a low power factor can occur.
All electrical and electronic equipment (including luminaires) connected to input mains must comply with EN 61000-3-2 standard.
IEC 1000-3-2 (1995)/ EN 61000-3-2 (1995) - specifies the limits for harmonic current created by equipment connected to public low voltage connected system. To establish limits for similar type of harmonic current distortion, equipment under test is categorized into four defined classes A, B, C, D. Class C consists of lighting equipment including dimming devices. The maximum permissible Harmonic current % for class C equipment are provide in Table 4.6

Table 4.6 Limits of Harmonic current for Class C equipment

Harmonic Order (n)	Max. permissible harmonic current expressed as % of input current
2	2
3	30*λ
5	10
7	7
9	5
11<n<39	3

λ- Circuit power factor

The harmonic limits are usually expressed in terms of THD rather than through single limits related to specific harmonics. It has been found that in most of the cases, THD was lower for non-dimmable LED luminaires. Many standard LED drivers produced by leading manufacturers operating with a wide input of AC voltage range, at the same time providing a wide range of output DC current as well as wide range of output DC voltage. It can be concluded that if the design of the power factor correction stage is made considering only normal operating conditions, it will lead to low power factor at low output powers. Therefore care should be taken that during manufacturing of smart LED luminaires, luminous efficacy or other performances are maintained at all operating conditions.

Conclusion

The prime aim of the project is to provide a cost-effective and energy efficient replacement of the current street lighting system. Identifying the causes for energy wastage of lamps, we have developed a system that provides the desired solution.

Our design consists of three main parts: motion detection sensors, wireless communication and power control of LED luminaires. In order to reduce energy expenditure our design consists of energy efficient and smart modules. We have included components with desirable features such as low cost, low power consumption and longer life-span. We have also integrated wireless communication network with appropriate range and very low power consumption. Moreover the low maintenance costs makes this project a profitable one.

According to the data received from the demo project and its use for the main project after varying the dimming profile, we found energy saving up to 67% and a payback period of 2.1 years. Better distribution and uniformity is also achieved from the road lighting design point of view. This demonstrates that our solution is feasible from the technical perspective. Further research also have to be conducted to find out advanced ways of controlling the system.

Therefore we can say that our project is not only a cost effective one but also adds smart features to the city for its overall development. Altogether we can say that the proposed solution solves the high energy consumption problem and also helps in protection of our biotic ecosystem.

Future Scope of Work

We know about the various advantages of smart street lighting, the extra benefits we are getting from smart applications. In addition to these benefits, there are some additional services which can be provided to the citizens with smart poles or the smart street luminaires in our project. Smart poles can be developed with telecom tower infrastructure to match with the city aesthetics and ready to accommodate modern technology as 4G, 5G, Wi Fi hotspot services for the city by converting the street light into public Hotspot services, Environmental sensors to monitor outdoor air quality, temperature, humidity, air quality index etc. and Electric vehicle charging points to charge and facilitate the use of electric vehicles in the city.

The current LED driver could be developed to a one which utilizes feedback to enhance the control of the output current. Although this system will become complex, it could provide more stability and allow more control over the intensity and hence could be advantageous to our system.

List of References

1. **'Road Lighting Fundamental Technology and Application' by Wout van Bommel, Springer Nature Publication 2014.**
2. **Energy Efficient Street Lighting guidelines, Bureau of Energy Efficiency India, Version 2.0 June 2010.**
3. **National Lighting Code 2010, Bureau of Indian Standards.**
4. **The SLL Lighting Handbook, The Society of Light and Lighting, Chartered Institutions of Building Service Engineers.**
5. **Website 'https://www.smartcities.gov.in' as seen on 25.04.2019.**
6. **Website 'https://www.tvilight.com' as seen on 30.03.2019 and data specification sheets.**
7. **Website 'https://www.citintelly.com' as seen on 10.04.2019 and technical specification sheets.**
8. **Lighting Controls Handbook Craig Dilouie by the Fairmount Press 2008.**
9. **Website 'https://standards.ieee.org/standard/802_15_4-2015-cor1-2018.html' as seen on 12.04.2019.**
10. **Website 'https://www.electronicsdesign.com' as seen on 12.04.2019.**
11. **BAJAJ Conventional Luminaires catalogue 2017.**
12. **BAJAJ LED luminaires catalogue 2018.**
13. **Luminous flux to input power ratio, power factor and Harmonics when dimming LED luminaires used in road lighting, A Djuretic, V Skerovic, N Arsic, M Kostic Lighting Res. Technol. 2019; 51: 304-323.**
14. **Compliance Testing to the IEC 1000-3-2 (EN 61000-3-2) and IEC 1000-3-3 (EN 61000-3-3) Standards.**

ANNEXURE

Case Study 1-a

DIALUX Report of road lighting design by HPSV luminaires

Partner for Contact:
Order No.:
Company:
Customer No.:

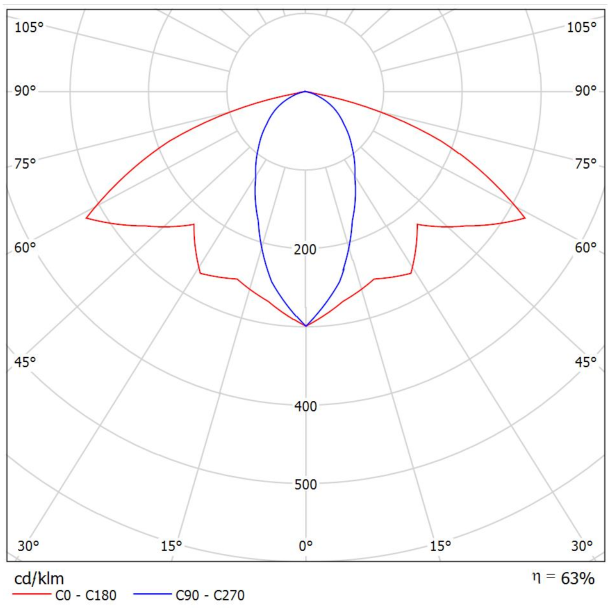
Date: 25.05.2019
Operator: Ranajit Bhattacharjee

Operator Ranajit Bhattacharjee
Telephone
Fax
e-Mail

BAJAJ BGEST 250SV FG SHN IP66 / Luminaire Data Sheet

See our luminaire catalog for an image of the luminaire.

Luminous emittance 1:

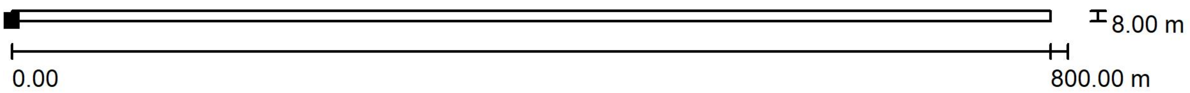


Luminaire classification according to CIE: 100
CIE flux code: 47 78 97 100 63

Due to missing symmetry properties, no UGR table can be displayed for this luminaire.

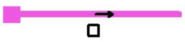
Operator Ranajit Bhattacharjee
Telephone
Fax
e-Mail

Exterior Scene 1 / Service Road / Value Chart (E)



Values in Lux, Scale 1 : 5720

Not all calculated values could be displayed.

Position of surface in external scene: 
Marked point:
(417.029 m, 1000.000 m, 0.000 m)

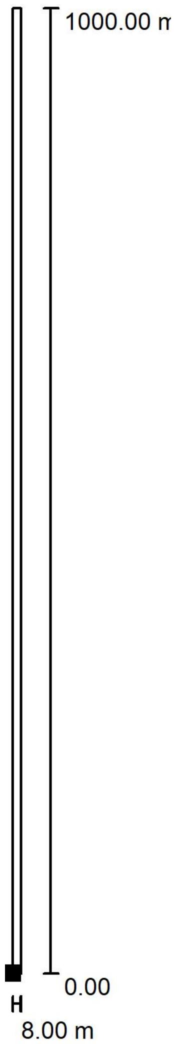
Grid: 10 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
27	23	31	0.833	0.729

Rotation: 0.0°

Operator Ranajit Bhattacharjee
Telephone
Fax
e-Mail

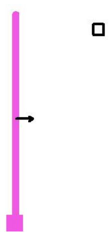
Exterior Scene 1 / Central Road 1 / Value Chart (E)



Values in Lux, Scale 1 : 7820

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(409.000 m, 0.002 m, 0.000 m)



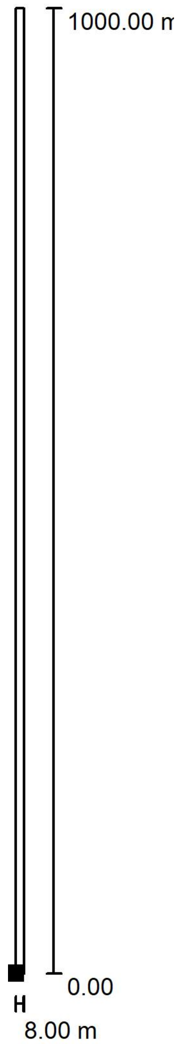
Grid: 10 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
39	20	52	0.522	0.393

Rotation: 0.0°

Operator Ranajit Bhattacharjee
Telephone
Fax
e-Mail

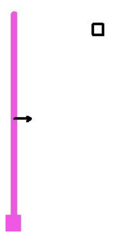
Exterior Scene 1 / Central Road 2 / Value Chart (E)



Values in Lux, Scale 1 : 7820

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(400.000 m, 0.024 m, 0.000 m)



Grid: 10 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
39	20	52	0.522	0.393

Rotation: 0.0°

Case Study 1-b

DIALUX Report of road lighting design by MH luminaires

Partner for Contact:
Order No.:
Company:
Customer No.:

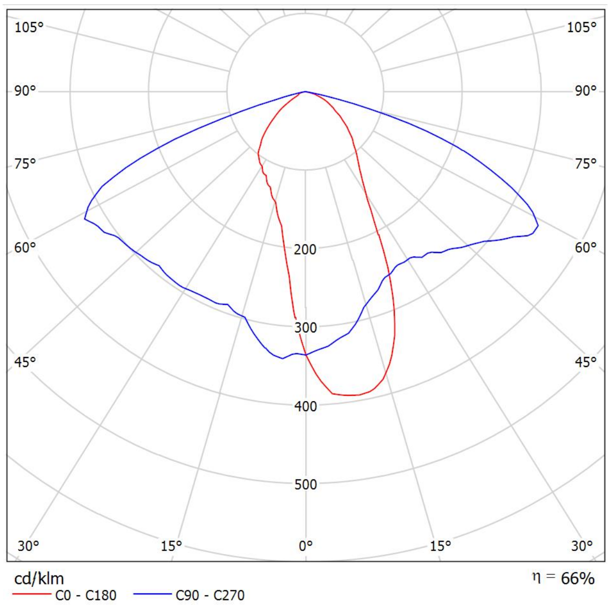
Date: 25.05.2019
Operator: Ranajit Bhattacharjee

Operator Ranajit Bhattacharjee
Telephone
Fax
e-Mail

PHILIPS CRP 330/1X250W / Luminaire Data Sheet

Luminous emittance 1:

See our luminaire catalog for an image of the luminaire.

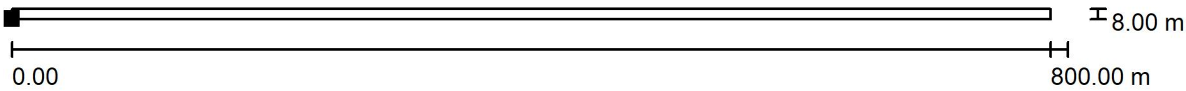


Luminaire classification according to CIE: 100
CIE flux code: 50 84 99 100 66

Due to missing symmetry properties, no UGR table can be displayed for this luminaire.

Operator Ranajit Bhattacharjee
Telephone
Fax
e-Mail

Exterior Scene 1 / Service Road / Value Chart (E)



Values in Lux, Scale 1 : 5720

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(417.250 m, 1000.000 m, 0.000 m)

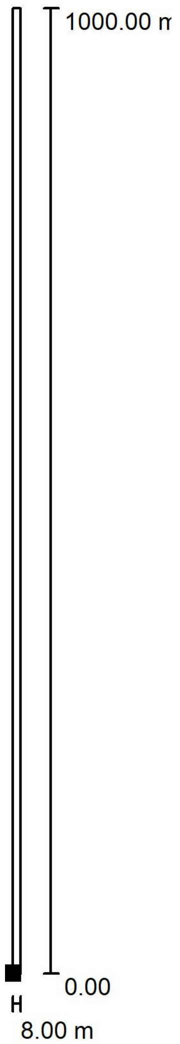
Grid: 10 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
32	24	36	0.757	0.666

Rotation: 0.0°

Operator Ranajit Bhattacharjee
Telephone
Fax
e-Mail

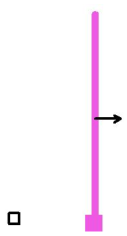
Exterior Scene 1 / Central Road 1 / Value Chart (E)



Values in Lux, Scale 1 : 7820

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(409.000 m, -0.001 m, 0.000 m)



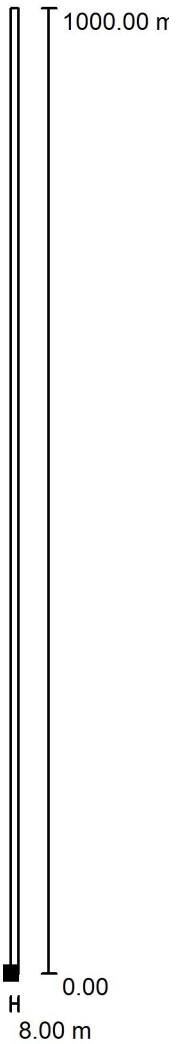
Grid: 10 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
37	25	48	0.681	0.530

Rotation: 0.0°

Operator Ranajit Bhattacharjee
Telephone
Fax
e-Mail

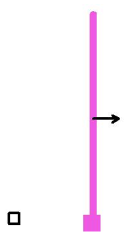
Exterior Scene 1 / Central Road 2 / Value Chart (E)



Values in Lux, Scale 1 : 7820

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(400.000 m, 0.000 m, 0.000 m)



Grid: 10 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
37	25	48	0.681	0.530

Rotation: 0.0°

Case Study 1-c

DIALUX Report of road lighting design by LED luminaires

Partner for Contact:
Order No.:
Company:
Customer No.:

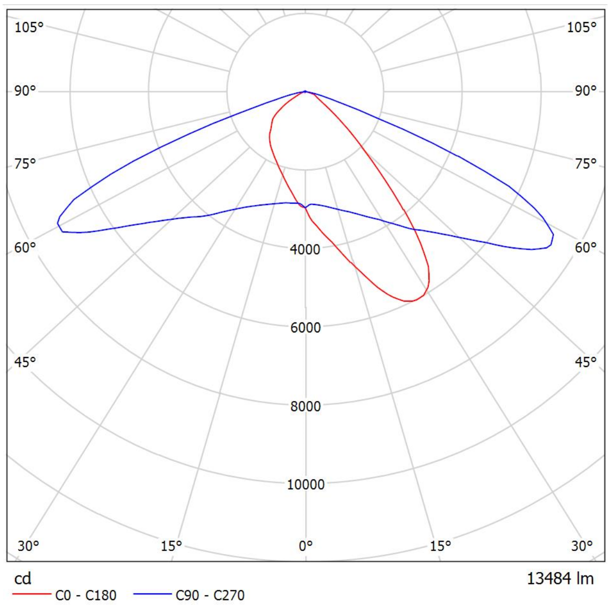
Date: 25.05.2019
Operator: Ranajit Bhattacharjee

Operator Ranajit Bhattacharjee
Telephone
Fax
e-Mail

BAJAJ 14265 BRTFG 140W LED / Luminaire Data Sheet

Luminous emittance 1:

See our luminaire catalog for an image of the luminaire.

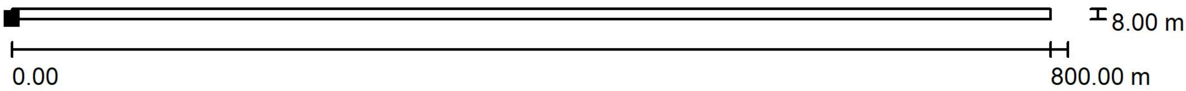


Luminaire classification according to CIE: 100
CIE flux code: 43 82 99 100 100

Due to missing symmetry properties, no UGR table can be displayed for this luminaire.

Operator Ranajit Bhattacharjee
Telephone
Fax
e-Mail

Exterior Scene 1 / Service Road / Value Chart (E)



Values in Lux, Scale 1 : 5720

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(416.801 m, 1000.000 m, 0.000 m)

Grid: 10 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
29	25	33	0.846	0.746

Rotation: 0.0°

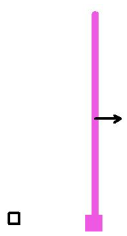
Operator Ranajit Bhattacharjee
Telephone
Fax
e-Mail

Exterior Scene 1 / Central Road 1 / Value Chart (E)

Values in Lux, Scale 1 : 7820

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(409.000 m, -0.029 m, 0.000 m)



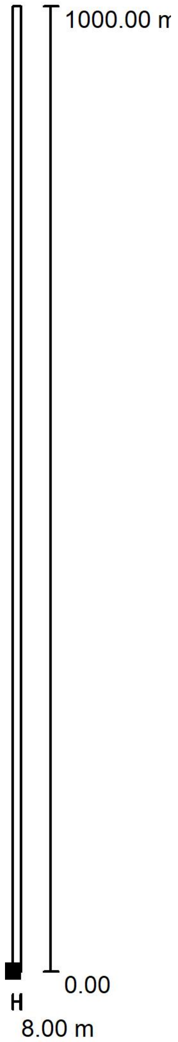
Grid: 10 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
34	30	36	0.893	0.838

Rotation: 0.0°

Operator Ranajit Bhattacharjee
Telephone
Fax
e-Mail

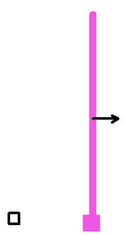
Exterior Scene 1 / Central Road 2 / Value Chart (E)



Values in Lux, Scale 1 : 7820

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(400.000 m, -0.025 m, 0.000 m)



Grid: 10 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
34	30	36	0.893	0.839

Rotation: 0.0°

City Manager Software data for a Weekday				
Date	**Time**	**Type of Dimming**	**Dimming % & Operating Time**	**No of Triggers**
04-02-2019	**23:56**	**Dynamic Dimming**	**10 % for 00:05:47**	**4, 12, 15, 16, 0, 0 / 0**
			80 % for 00:09:13	
04-02-2019	**23:41**	**Dynamic Dimming**	**10 % for 00:05:58**	**7, 15, 16, 24, 0, 0 / 0**
			80 % for 00:09:02	
04-02-2019	**23:26**	**Dynamic Dimming**	**80 % for 00:06:21**	**4, 7, 7, 15, 0, 0 / 0**
			10 % for 00:08:40	
04-02-2019	**23:11**	**Dynamic Dimming**	**100 % for 00:02:42**	**21, 16, 7, 27, 0, 0 / 0**
			20 % for 00:01:14	
			80 % for 00:06:59	
			10 % for 00:04:05	
04-02-2019	**22:56**	**Dynamic Dimming**	**100 % for 00:11:52**	**40, 14, 4, 34, 0, 0 / 0**
			20 % for 00:03:08	
04-02-2019	**22:41**	**Dynamic Dimming**	**20 % for 00:06:43**	**12, 11, 4, 18, 0, 0 / 0**
			100 % for 00:08:16	
04-02-2019	**22:26**	**Dynamic Dimming**	**100 % for 00:09:44**	**19, 16, 10, 24, 0, 0 / 0**
			20 % for 00:05:17	
04-02-2019	**22:26**	**Dynamic Dimming**	**100 % for 00:09:44**	**19, 16, 10, 24, 0, 0 / 0**
			20 % for 00:05:17	
04-02-2019	**22:11**	**Dynamic Dimming**	**100 % for 00:11:56**	**34, 24, 10, 31, 0, 0 / 0**
			20 % for 00:03:03	
04-02-2019	**21:56**	**Dynamic Dimming**	**100 % for 00:13:13**	**49, 23, 8, 41, 0, 0 / 0**
			20 % for 00:01:48	
04-02-2019	**21:41**	**Dynamic Dimming**	**100 % for 00:14:53**	**53, 27, 19, 68, 0, 0 / 0**
			20 % for 00:00:07	
04-02-2019	**21:26**	**Dynamic Dimming**	**100 % for 00:14:40**	**41, 24, 16, 66, 0, 0 / 0**
			20 % for 00:00:19	
04-02-2019	**21:11**	**Dynamic Dimming**	**100 % for 00:14:54**	**54, 27, 15, 71, 0, 0 / 0**
			20 % for 00:00:07	
04-02-2019	**20:56**	**Dynamic Dimming**	**100 % for 00:15:00**	**45, 30, 28, 71, 0, 0 / 0**
04-02-2019	**20:41**	**Dynamic Dimming**	**100 % for 00:14:51**	**50, 30, 33, 79, 0, 0 / 0**
			20 % for 00:00:09	
04-02-2019	**20:26**	**Dynamic Dimming**	**100 % for 00:14:53**	**55, 39, 35, 76, 0, 0 / 0**
			20 % for 00:00:07	
04-02-2019	**20:11**	**Dynamic Dimming**	**100 % for 00:14:45**	**59, 39, 35, 74, 0, 0 / 0**
			20 % for 00:00:15	
04-02-2019	**19:56**	**Dynamic Dimming**	**100 % for 00:14:58**	**54, 45, 40, 81, 0, 0 / 0**
			20 % for 00:00:02	
04-02-2019	**19:41**	**Dynamic Dimming**	**100 % for 00:14:52**	**58, 38, 42, 79, 0, 0 / 0**
			20 % for 00:00:08	
04-02-2019	**19:26**	**Dynamic Dimming**	**100 % for 00:14:52**	**48, 43, 49, 76, 0, 0 / 0**
			20 % for 00:00:08	

04-02-2019	**19:11**	**Dynamic Dimming**	**100 % for 00:15:01**	**55, 44, 36, 80, 0, 0 / 0**
04-02-2019	**18:56**	**Dynamic Dimming**	**100 % for 00:15:00**	**36, 51, 48, 86, 0, 0 / 0**
04-02-2019	**18:41**	**Dynamic Dimming**	**100 % for 00:15:01**	**50, 43, 46, 75, 0, 0 / 0**
04-02-2019	**18:26**	**Dynamic Dimming**	**100 % for 00:15:00**	**49, 56, 51, 78, 0, 0 / 0**
04-02-2019	**18:11**	**Dynamic Dimming**	**100 % for 00:15:00**	**73, 50, 55, 80, 0, 0 / 0**
04-02-2019	**17:56**	**Dynamic Dimming**	**100 % for 00:15:00**	**67, 50, 55, 83, 0, 0 / 0**
04-02-2019	**17:41**	**Dynamic Dimming**	**100 % for 00:15:00**	**63, 59, 63, 84, 0, 0 / 0**
04-02-2019	**17:26**	**Dynamic Dimming**	**100 % for 00:15:01** **20 % for 00:00:06**	**47, 41, 53, 62, 0, 0 / 0**
04-02-2019	**17:11**	**Dynamic Dimming**	**100 % for 00:01:16**	**0, 0, 0, 0, 0, 0 / 0**
04-02-2019	**04:55**	**Dynamic Dimming**	**10 % for 00:14:38** **80 % for 00:00:22**	**0, 1, 0, 0, 0, 0 / 0**
04-02-2019	**04:40**	**Dynamic Dimming**	**10 % for 00:14:16** **80 % for 00:00:44**	**2, 2, 2, 2, 0, 0 / 0**
04-02-2019	**04:25**	**Dynamic Dimming**	**80 % for 00:00:48** **10 % for 00:14:12**	**1, 1, 1, 1, 0, 0 / 0**
04-02-2019	**04:10**	**Dynamic Dimming**	**10 % for 00:14:34** **80 % for 00:00:26**	**1, 1, 1, 1, 0, 0 / 0**
04-02-2019	**03:55**	**Dynamic Dimming**	**10 % for 00:15:00**	**0, 0, 0, 0, 0, 0 / 0**
04-02-2019	**03:40**	**Dynamic Dimming**	**10 % for 00:14:38** **80 % for 00:00:22**	**0, 1, 0, 0, 0, 0 / 0**
04-02-2019	**03:25**	**Dynamic Dimming**	**10 % for 00:13:01** **80 % for 00:01:59**	**7, 1, 1, 3, 0, 0 / 0**
04-02-2019	**03:10**	**Dynamic Dimming**	**10 % for 00:14:38** **80 % for 00:00:22**	**1, 0, 0, 0, 0, 0 / 0**
04-02-2019	**02:55**	**Dynamic Dimming**	**10 % for 00:15:01**	**0, 0, 0, 0, 0, 0 / 0**
04-02-2019	**02:40**	**Dynamic Dimming**	**10 % for 00:12:20** **80 % for 00:02:41**	**9, 1, 1, 2, 0, 0 / 0**
04-02-2019	**02:25**	**Dynamic Dimming**	**10 % for 00:12:54** **80 % for 00:02:05**	**6, 0, 0, 1, 0, 0 / 0**
04-02-2019	**02:10**	**Dynamic Dimming**	**10 % for 00:14:16** **80 % for 00:00:44**	**1, 0, 1, 0, 0, 0 / 0**
04-02-2019	**01:55**	**Dynamic Dimming**	**10 % for 00:09:39** **80 % for 00:05:21**	**14, 2, 1, 6, 0, 0 / 0**
04-02-2019	**01:40**	**Dynamic Dimming**	**80 % for 00:02:39** **10 % for 00:12:21**	**6, 0, 2, 2, 0, 0 / 0**
04-02-2019	**01:25**	**Dynamic Dimming**	**80 % for 00:03:06** **10 % for 00:11:54**	**6, 4, 1, 6, 0, 0 / 0**
04-02-2019	**01:10**	**Dynamic Dimming**	**80 % for 00:04:29** **10 % for 00:10:32**	**13, 4, 1, 9, 0, 0 / 0**
04-02-2019	**00:55**	**Dynamic Dimming**	**10 % for 00:12:07** **80 % for 00:02:53**	**5, 1, 3, 1, 0, 0 / 0**
04-02-2019	**00:40**	**Dynamic Dimming**	**10 % for 00:08:14**	**17, 3, 7, 2, 0, 0 / 0**

			80 % for 00:06:45	
04-02-2019	**00:25**	**Dynamic Dimming**	**10 % for 00:09:39**	**15, 0, 2, 1, 0, 0 / 0**
			80 % for 00:05:21	
04-02-2019	**00:10**	**Dynamic Dimming**	**80 % for 00:09:56**	**25, 5, 7, 21, 0, 0 / 0**
			10 % for 00:05:04	

City Manager Data for a Sunday				
Date	**Time**	**Type of Dimming**	**Dimming % & Operating Time**	**No of Triggers**
31-03-19	**23:56**	**Dynamic Dimming**	**80 % for 00:13:36**	**15, 15, 39, 51, 0, 0 / 0**
			10 % for 00:01:24	
31-03-19	**23:41**	**Dynamic Dimming**	**80 % for 00:14:21**	**14, 25, 23, 55, 0, 0 / 0**
			10 % for 00:00:41	
31-03-19	**23:26**	**Dynamic Dimming**	**80 % for 00:13:12**	**10, 18, 30, 52, 0, 0 / 0**
			10 % for 00:01:54	
31-03-19	**23:11**	**Dynamic Dimming**	**100 % for 00:03:31**	**10, 6, 44, 59, 0, 0 / 0**
			20 % for 00:00:20	
			80 % for 00:10:56	
			10 % for 00:00:13	
31-03-19	**22:56**	**Dynamic Dimming**	**100 % for 00:13:56**	**7, 22, 19, 62, 0, 0 / 0**
			20 % for 00:01:08	
31-03-19	**22:41**	**Dynamic Dimming**	**100 % for 00:14:24**	**12, 27, 22, 66, 0, 0 / 0**
			20 % for 00:00:37	
31-03-19	**22:26**	**Dynamic Dimming**	**100 % for 00:14:44**	**9, 32, 30, 71, 0, 0 / 0**
			20 % for 00:00:15	
31-03-19	**22:11**	**Dynamic Dimming**	**100 % for 00:13:52**	**2, 33, 21, 49, 0, 0 / 0**
			20 % for 00:01:10	
31-03-19	**21:56**	**Dynamic Dimming**	**100 % for 00:14:30**	**8, 43, 26, 64, 0, 0 / 0**
			20 % for 00:00:30	
31-03-19	**21:41**	**Dynamic Dimming**	**100 % for 00:14:52**	**7, 49, 30, 78, 0, 0 / 0**
			20 % for 00:00:08	
31-03-19	**21:26**	**Dynamic Dimming**	**100 % for 00:14:51**	**9, 61, 37, 82, 0, 0 / 0**
			20 % for 00:00:09	
31-03-19	**21:11**	**Dynamic Dimming**	**100 % for 00:14:43**	**6, 46, 38, 67, 0, 0 / 0**
			20 % for 00:00:17	
31-03-19	**20:56**	**Dynamic Dimming**	**100 % for 00:15:00**	**14, 55, 37, 75, 0, 0 / 0**
31-03-19	**20:41**	**Dynamic Dimming**	**100 % for 00:15:00**	**13, 52, 45, 69, 0, 0 / 0**
31-03-19	**20:26**	**Dynamic Dimming**	**100 % for 00:15:00**	**20, 54, 51, 78, 0, 0 / 0**
31-03-19	**20:11**	**Dynamic Dimming**	**100 % for 00:15:03**	**39, 57, 49, 78, 0, 0 / 0**
			20 % for 00:00:04	
31-03-19	**19:55**	**Dynamic Dimming**	**100 % for 00:15:00**	**42, 57, 63, 84, 0, 0 / 0**
31-03-19	**19:40**	**Dynamic Dimming**	**100 % for 00:15:00**	**37, 56, 67, 86, 0, 0 / 0**
31-03-19	**19:25**	**Dynamic Dimming**	**100 % for 00:15:00**	**40, 56, 61, 86, 0, 0 / 0**
31-03-19	**19:10**	**Dynamic Dimming**	**100 % for 00:15:00**	**63, 62, 64, 84, 0, 0 / 0**
31-03-19	**18:55**	**Dynamic Dimming**	**100 % for 00:14:59**	**67, 55, 66, 87, 0, 0 / 0**
31-03-19	**18:40**	**Dynamic Dimming**	**100 % for 00:15:01**	**78, 56, 57, 84, 0, 0 / 0**
31-03-19	**18:25**	**Dynamic Dimming**	**100 % for 00:15:00**	**74, 62, 67, 85, 0, 0 / 0**
31-03-19	**18:10**	**Dynamic Dimming**	**100 % for 00:15:00**	**73, 66, 76, 86, 0, 0 / 0**
31-03-19	**17:55**	**Dynamic Dimming**	**100 % for 00:15:00**	**65, 63, 79, 88, 0, 0 / 0**

31-03-19	17:40	Dynamic Dimming	100 % for 00:15:01	54, 56, 78, 85, 0, 0 / 0
31-03-19	17:25	Dynamic Dimming	100 % for 00:15:04	30, 39, 60, 65, 0, 0 / 0
31-03-19	17:10	Dynamic Dimming	100 % for 00:01:16	0, 0, 0, 0, 0, 0 / 0
31-03-19	08:57	Dynamic Dimming	100 % for 00:15:00	82, 59, 75, 89, 0, 0 / 0
31-03-19	08:42	Dynamic Dimming	100 % for 00:15:01	75, 69, 82, 90, 0, 0 / 0
31-03-19	08:27	Dynamic Dimming	100 % for 00:15:05	62, 55, 60, 69, 0, 0 / 0
31-03-19	08:12	Dynamic Dimming	100 % for 00:01:17	0, 0, 0, 0, 0, 0 / 0
31-03-19	04:55	Dynamic Dimming	80 % for 00:14:04 10 % for 00:00:56	58, 0, 8, 50, 0, 0 / 0
31-03-19	04:40	Dynamic Dimming	80 % for 00:14:29 10 % for 00:00:32	63, 1, 5, 55, 0, 0 / 0
31-03-19	04:25	Dynamic Dimming	80 % for 00:10:41 10 % for 00:04:19	41, 1, 0, 38, 0, 0 / 0
31-03-19	04:10	Dynamic Dimming	80 % for 00:12:22 10 % for 00:02:38	52, 7, 1, 46, 0, 0 / 0
31-03-19	03:55	Dynamic Dimming	80 % for 00:11:12 10 % for 00:03:48	43, 3, 1, 18, 0, 0 / 0
31-03-19	03:40	Dynamic Dimming	80 % for 00:10:27 10 % for 00:04:33	47, 6, 3, 27, 0, 0 / 0
31-03-19	03:25	Dynamic Dimming	80 % for 00:11:18 10 % for 00:03:42	46, 4, 5, 34, 0, 0 / 0
31-03-19	03:10	Dynamic Dimming	80 % for 00:13:45 10 % for 00:01:14	56, 9, 12, 45, 0, 0 / 0
31-03-19	02:55	Dynamic Dimming	10 % for 00:01:19 80 % for 00:13:41	63, 9, 6, 43, 0, 0 / 0
31-03-19	02:40	Dynamic Dimming	80 % for 00:14:34 10 % for 00:00:26	59, 8, 16, 63, 0, 0 / 0
31-03-19	02:25	Dynamic Dimming	80 % for 00:12:52 10 % for 00:02:09	48, 7, 13, 49, 0, 0 / 0
31-03-19	02:10	Dynamic Dimming	80 % for 00:13:08 10 % for 00:01:52	55, 8, 10, 48, 0, 0 / 0
31-03-19	01:55	Dynamic Dimming	80 % for 00:14:04 10 % for 00:00:56	61, 4, 13, 50, 0, 0 / 0
31-03-19	01:40	Dynamic Dimming	80 % for 00:12:13 10 % for 00:02:47	50, 9, 4, 24, 0, 0 / 0
31-03-19	01:25	Dynamic Dimming	80 % for 00:10:49 10 % for 00:04:11	45, 6, 2, 34, 0, 0 / 0
31-03-19	01:10	Dynamic Dimming	10 % for 00:02:49 80 % for 00:12:11	54, 5, 7, 50, 0, 0 / 0
31-03-19	00:55	Dynamic Dimming	80 % for 00:13:45 10 % for 00:01:15	56, 8, 13, 57, 0, 0 / 0
31-03-19	00:40	Dynamic Dimming	80 % for 00:14:10 10 % for 00:00:50	54, 9, 17, 55, 0, 0 / 0

31-03-19	**00:25**	**Dynamic Dimming**	**80 % for 00:13:38**	**50, 7, 17, 54, 0, 0 / 0**
			10 % for 00:01:22	
31-03-19	**00:10**	**Dynamic Dimming**	**80 % for 00:14:19**	**56, 12, 35, 64, 0, 0 / 0**
			10 % for 00:00:42	